THE PHYSICAL PHENOMENA

OF

HARBOR ENTRANCES.

THEIR CAUSES AND REMEDIES.

DEFECTS OF PRESENT METHODS OF IMPROVEMENT.

By Lewis M. Haupt, C.E.
(*Professor of Civil Engineering, University of Pennsylvania, Phila.*)

This Paper was awarded the Magellanic Premium at a Stated Meeting of the American Philosophical Society, held December 16, 1887.

Every well-considered plan for improving the entrance to a harbor must take into account the existing physical conditions or features of the site, and the causes which have produced them. These features are composed of the land-drainage, the inner basin, the gorge, the outer basin, the bar and the ocean. In passing from the fresh to the salt water system, there may be one or more channels having some peculiar characteristics, which are not mere accidents, but the results of certain forces. Before any radical or permanent improvement can be effected it is necessary that the forces operating at any point should be fully understood, and, so far as possible, be measured. In tracing step by step the causes from their effects, I have found the circle of investigation unavoidably widening, until it embraced many of the physical phenomena pertaining to the North Atlantic Ocean.

The initial point in this study is the form of the bed or mould of alluvial harbors, supposed to be of material sufficiently plastic to reveal the effect of the forces operating upon them. I have heretofore elsewhere called attention to the important deductions to be obtained from noting the position of

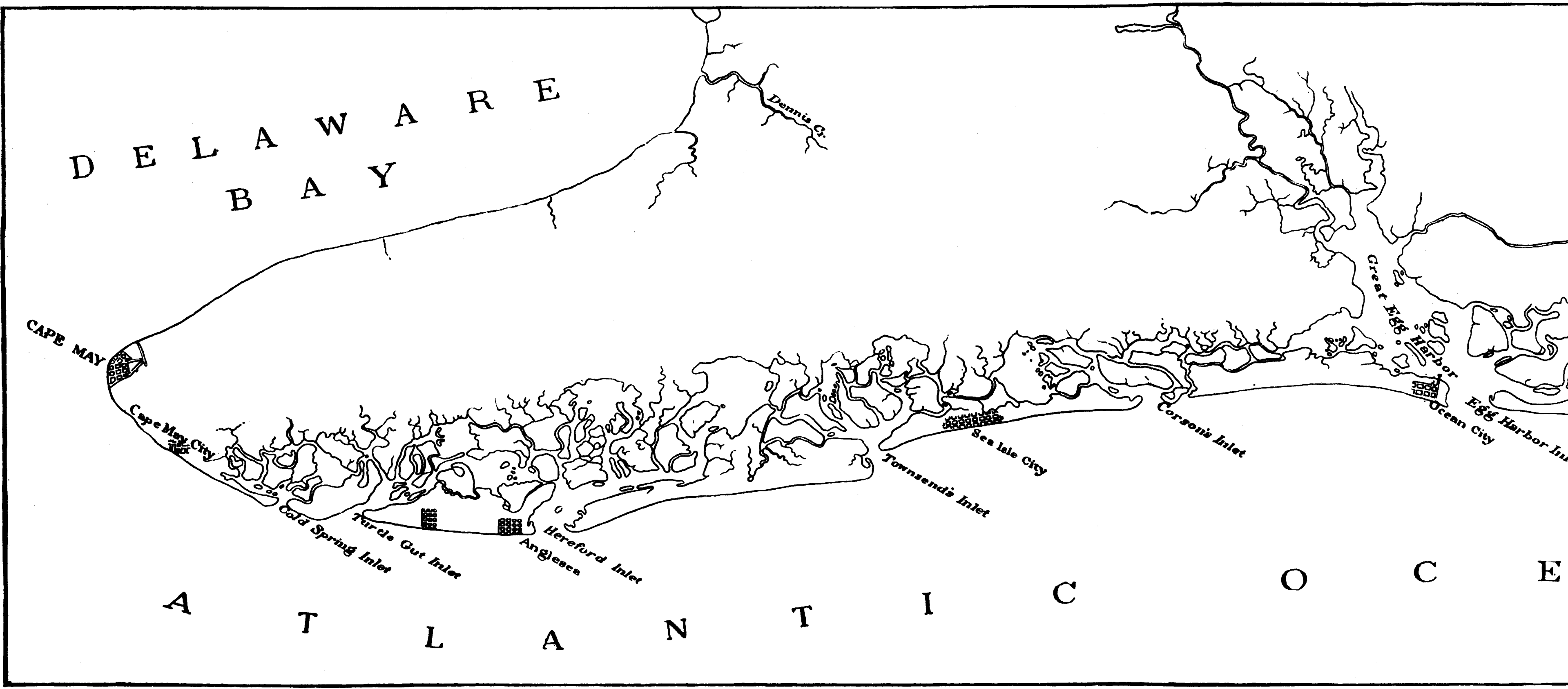
the submerged crest line of bars, as well as from the relative slopes of sections along the thalweg of the channel or across the bar, as indicating the direction of movement of the sand and of the flexure of the outer ends of the channels, after passing the gorge, either up or down the coast. The immediate cause of this flexure was asserted to be a littoral component which *rolled up the sand on the flood tide and compressed the ebb stream against one or other of the adjacent shores.* But why this resultant should have been so constantly operating in opposite directions at different entrances was not then fully understood or stated.

It is the object of this paper to collate certain observed facts, for the purpose of explaining these phenomena and of deducing therefrom a conclusion of practical value in the economical solution of the problem of improving our harbor entrances.

Typical Forms. (See Plate I.)

In examining the plan of any entrance it is generally found that the ends of the islands forming the outlying cordon are elongated into spits or hooks, curving inward, with a smooth outer and a rugged inner shore line; that one of the points is sharp, and the other blunt or round headed; that the sharp point usually recedes from the general coast line; that the seaward slope of a cross section of the bar is less steep than the inner slope, except where the ebb streams cross it; that the flood tide usually approaches the entrance at first in a direction more nearly parallel to the sharper lip and normal to the blunt one, rolling up the gentler slope and depositing sand on or within the crest of the bar, where "breakers" are found; that along the shore of the sharp point there is a shallow channel cut out by the flood, and curving around the blunt, projecting lip of the gorge there is the main deep-water chan-


New Inlet
Great Bay
Brigantine Inlet
Absecon Inlet (Atlantic City Harbor)
Atlantic City
Egg Harbor Inlet
Ocean City
Great Egg Harbor
Corson's Inlet
Sea Isle City
Townsend's Inlet
IC OCEAN


DELAWARE
BAY
Dennis Cr.
CAPE MAY
Cape May City
Cold Spring Inlet
Turtle Gut Inlet
Anglesea
Hereford Inlet
Townsend's Inlet
Sea Isle City
Corson's Inlet
Great Egg Harbor
Ocean City
Egg Harbor In
ATLANTIC OCE

nel produced by the ebb. Between these limits are found one or more secondary or swash channels, which provide egress for the lateral overflow, so to speak, of the ebb and correspond to the waste weirs or crevasses of a stream.

Charleston Harbor.

These characteristics are well illustrated in the harbor of Charleston, S. C., as seen on the chart of 1858 (Fig. 1). I have selected this early date as it shows the current movements and condition of channels before extensive improvements were begun. Here the thalweg approaches the gorge in a direction nearly east and west, and on passing out it is deflected fully 90°, and extends nearly north and south. Hugging the northern spit is the flood channel, known as Maffit's or Sullivan's Island channel, with nine (9) feet on its crest at the *inner* end. Then appear the breakers of Drunken Dick shoal, followed by the weir channels known as the North channel, with ten (10) feet at its *outer* end; the swash channel, nine (9) feet; the main ship channel, eleven (11) feet, and Lawford's channel, ten (10) feet.

The shortest distance to the outer eighteen (18) feet contour from the gorge is three and one-fourth ($3\frac{1}{4}$) statute miles, whilst by the main ship channel courses it is *seven* (7) miles, or more than double, so that vessels entering from the north must make a detour of nearly fourteen (14) miles to cross the bar.

At the only current station outside the bar the set of the flood during the first and second quarters (its most energetic period) is *parallel to the shore* of Sullivan's Island, or about west south-west, but it swings around through west to nearly north-west, or normal to the gorge during the last quarter. The stations inside of and on the bar show

local modifications of the flood and a movement towards the entrance, due to the diminution of resistance in that direction, especially during the last quarters of the flood. The plane of maximum ebb scour, as indicated by the depth of water on the bar, is limited to about twelve (12) feet.

Similar features will be noticed at Galveston (Fig. 2) and at other entrances, but it does not always happen that the crossing of the bar is so far from the gorge, nor is it always to the south. The position of this important point is the resultant of the internal and external forces which affect the movement of the main ebb stream.

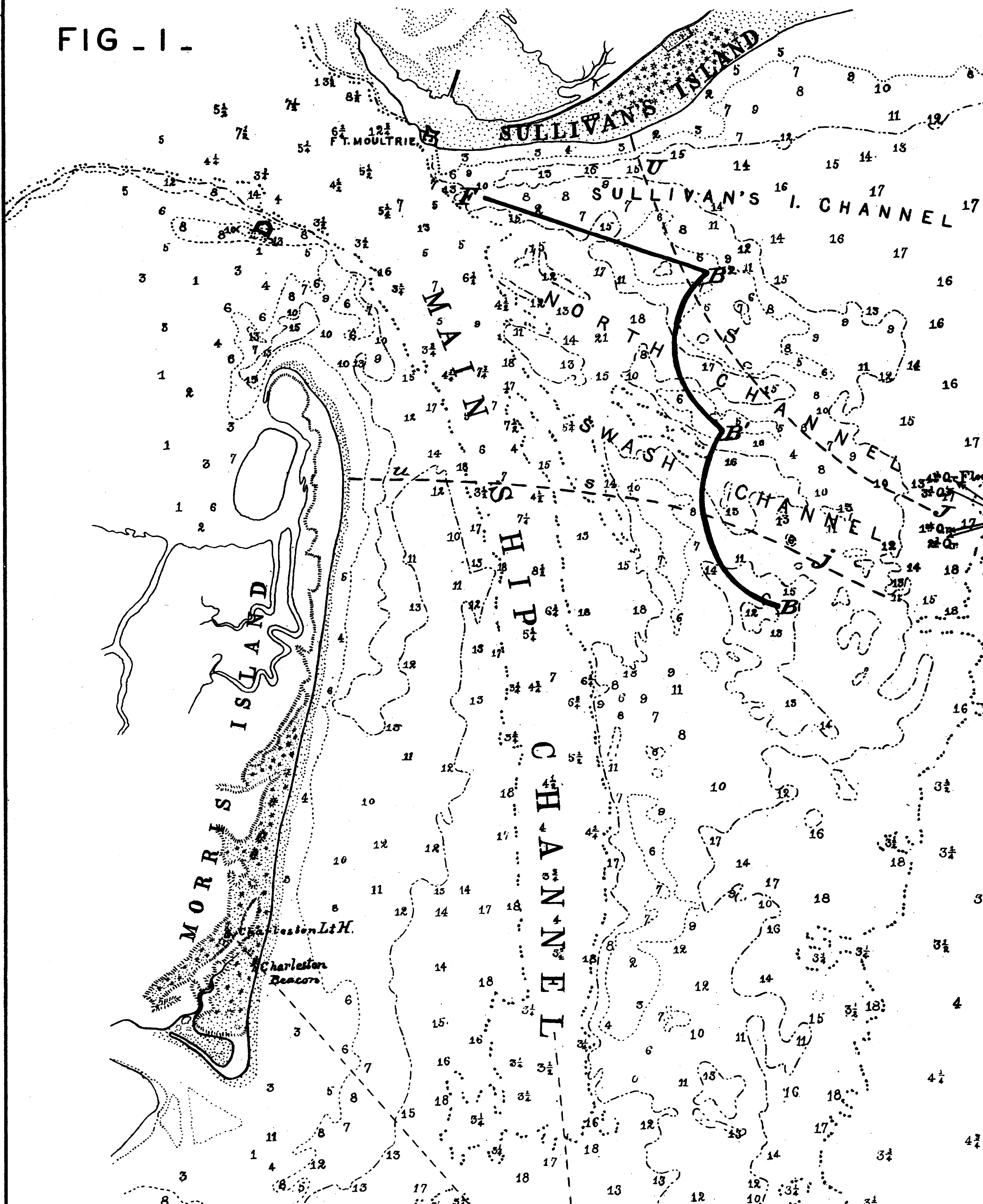
The Forces.

The *internal* forces are those resulting from the form and extent of the inner basin, the volume of the tidal prism and the relative directions of the tidal and river currents as they approach the gorge. The *external* effects are those resulting from the form, position and extent of the banks which have been piled up by the flood and obstruct the ebb. Hence it follows, if the flood pressure and movement is from the south side of the entrance the channel will be to the north, as the banks will be more extensive on the former side, offering greater resistance and deflecting the ebb stream and crowding it in until it is supported on its opposite flank by the shore. If the flood resultant comes in from the northern side, the reverse is true.

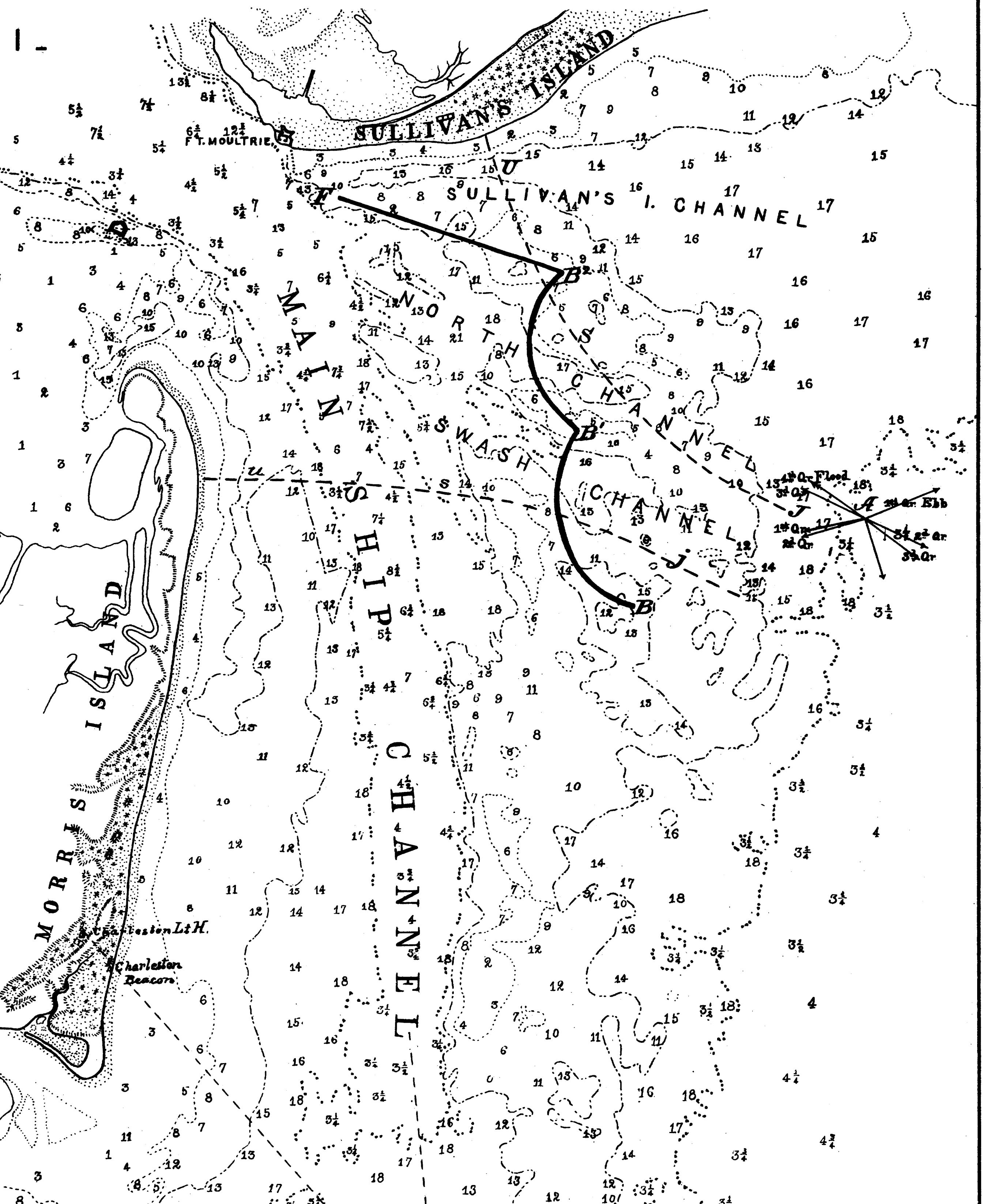
Again, if the confluent ebb streams of the inner basin are so directed by natural or artificial constructions as to commingle and unite their energies, instead of opposing one another, as most frequently occurs, the momentum of the united stream will be greater and the crossing on the bar be consequently deepened. This will be better understood by observing that the inner

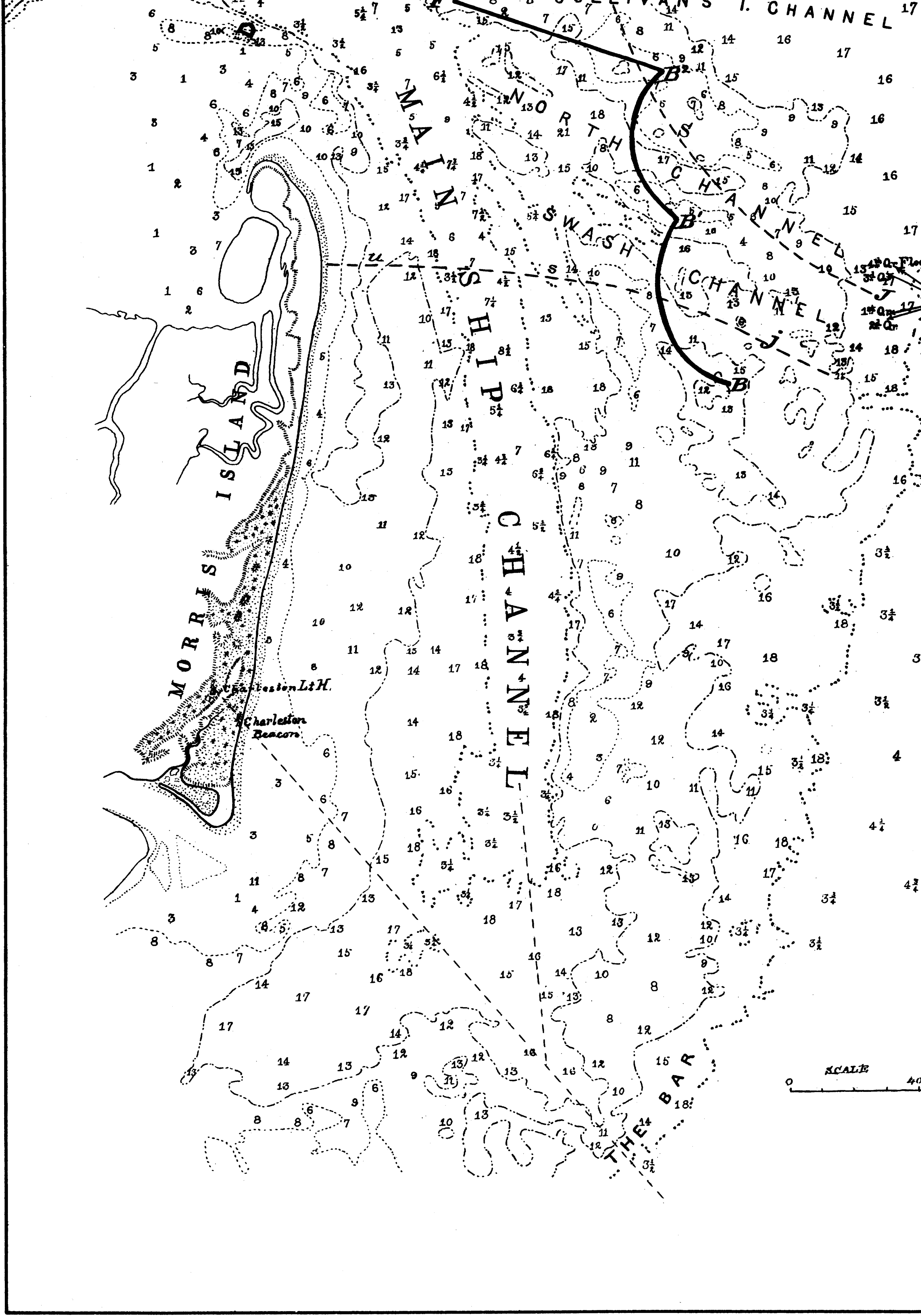
Entrance to Charleston Harbor, S,C,

FIG _ I _

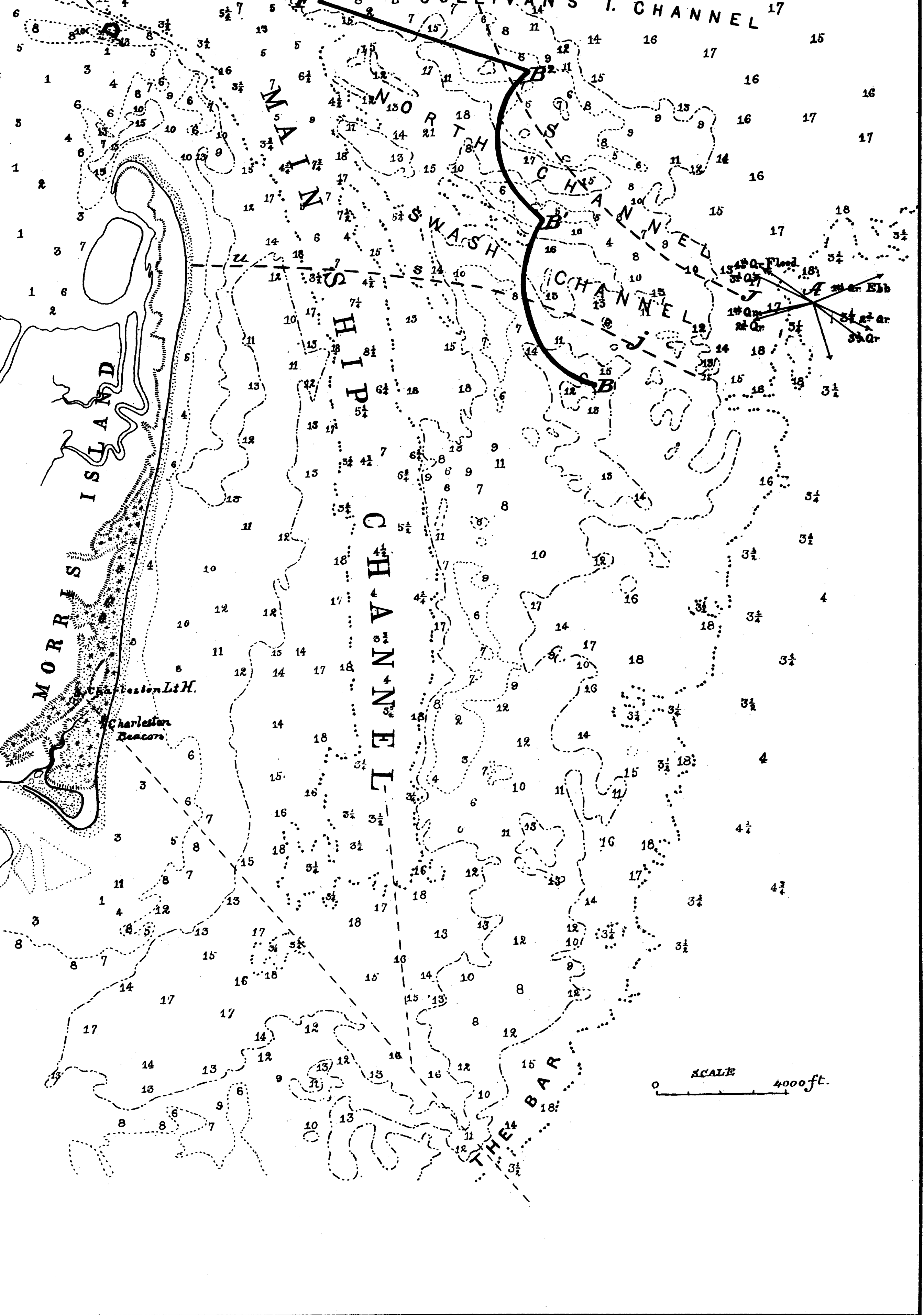


Entrance to Charleston Harbor, S,C,





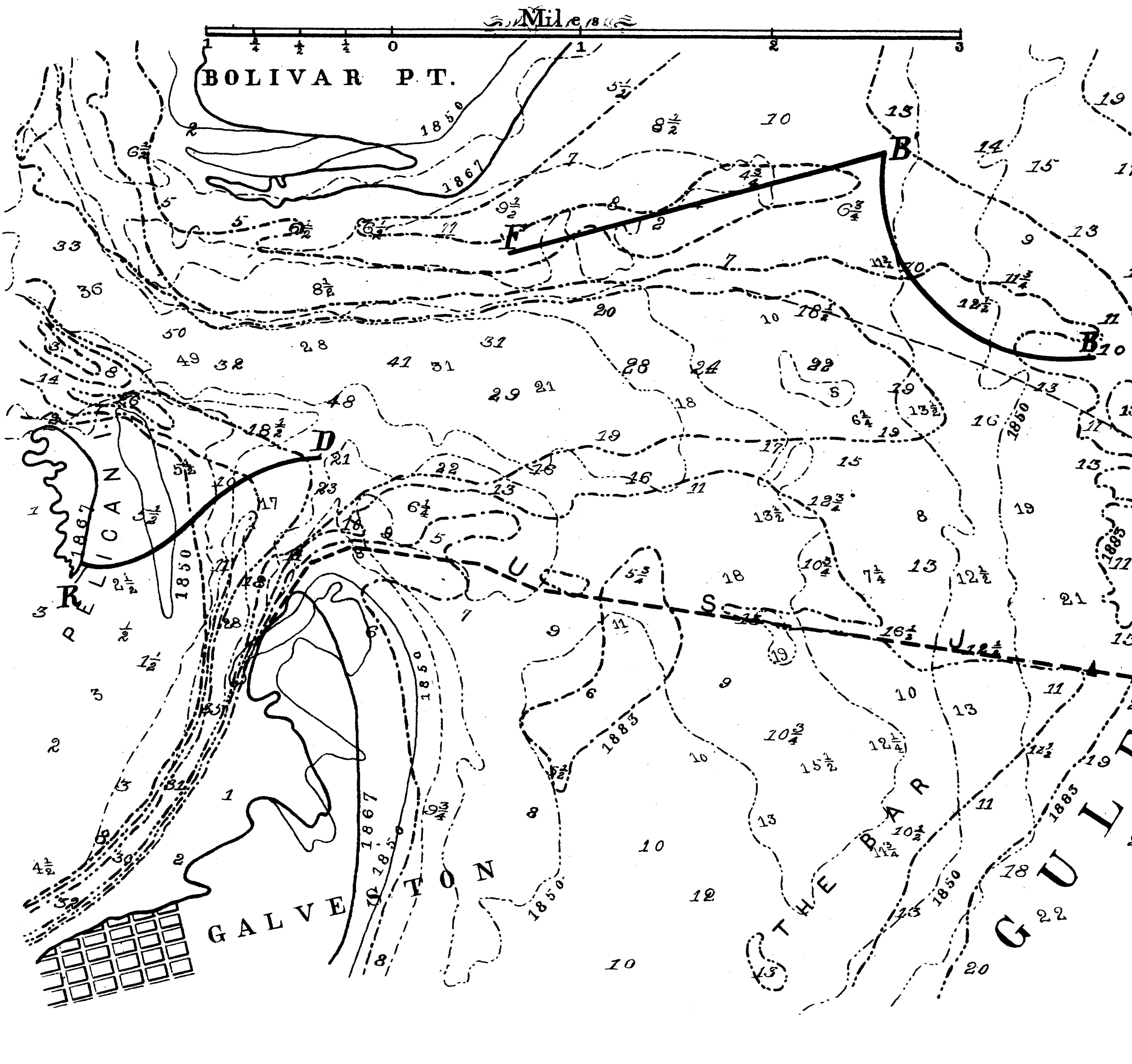
I. CHANNEL
MAIN SHIP CHANNEL
NORTH CHANNEL
SWASH CHANNEL
MORRIS ISLAND
Charleston Lt H.
Charleston Beacon
THE BAR
SCALE



CHANNEL
NORTH CHANNEL
SWASH CHANNEL
MAIN SHIP CHANNEL
MORRIS ISLAND
Charleston Lt H.
Charleston Beacon
THE BAR
Flood
Ebb
SCALE
4000 ft.

Entrance to Galveston Harbor, Texas,

FIG _ II _



Entrance to Galveston Harbor, Texas,

FIG _ II _

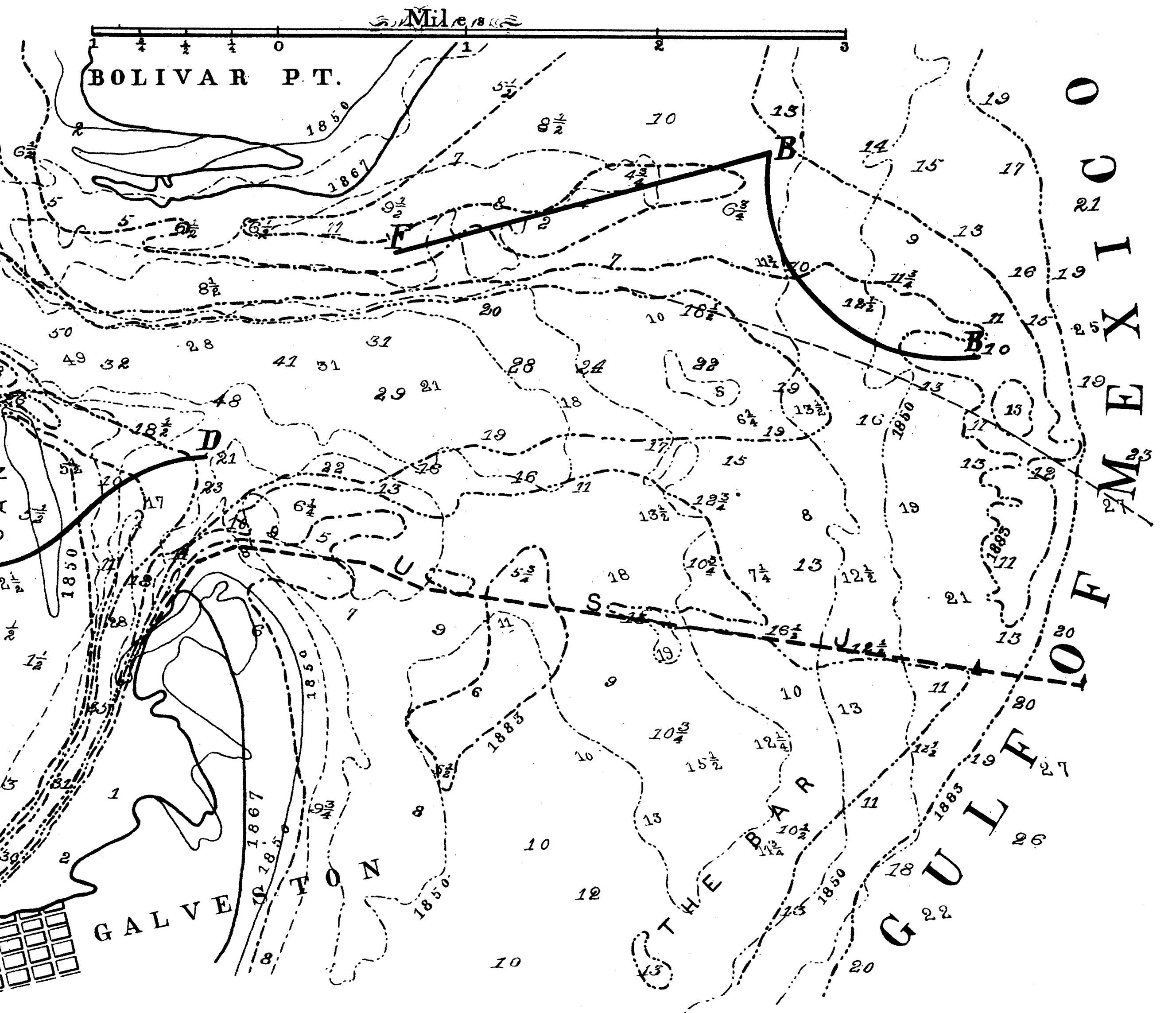
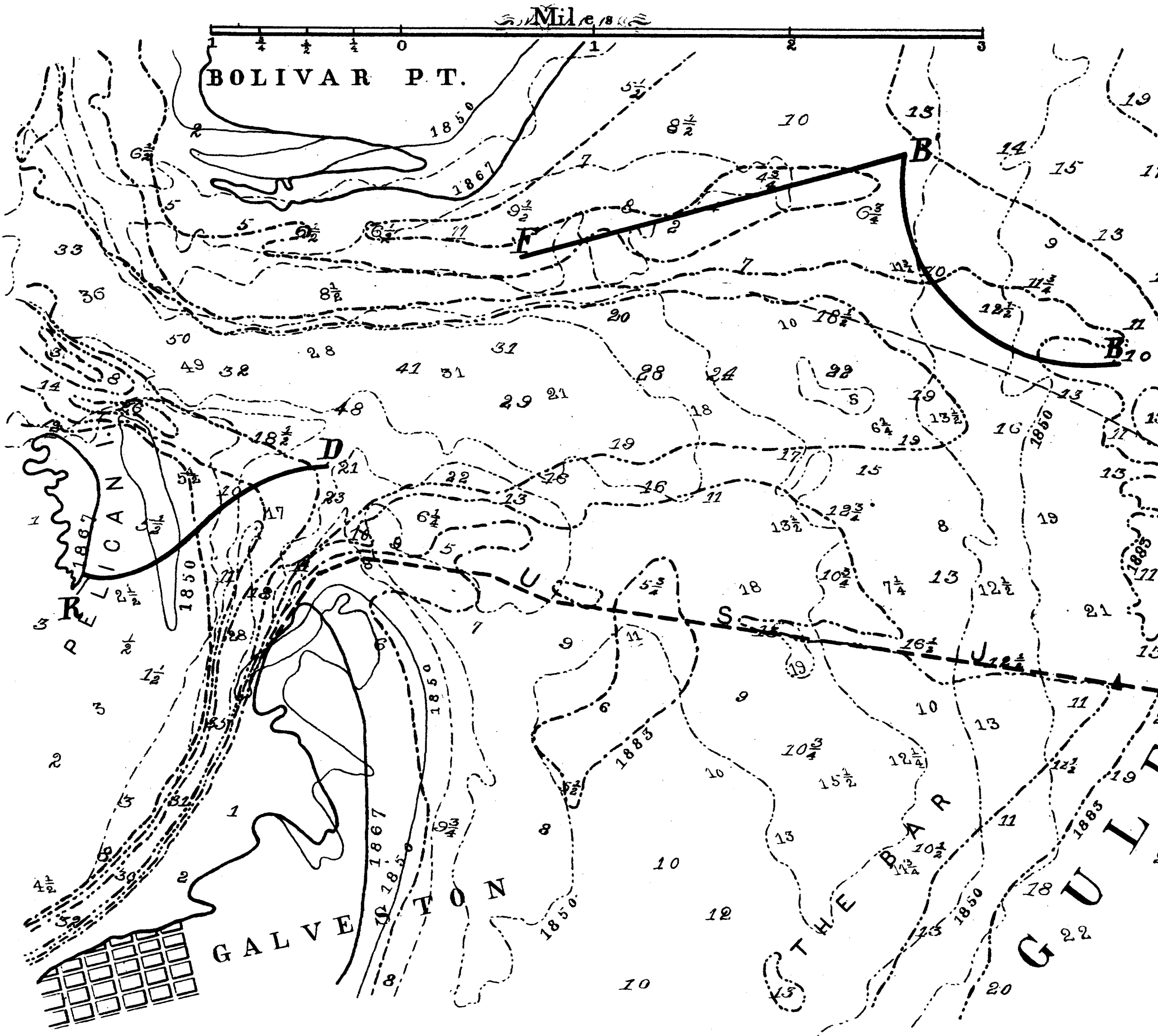
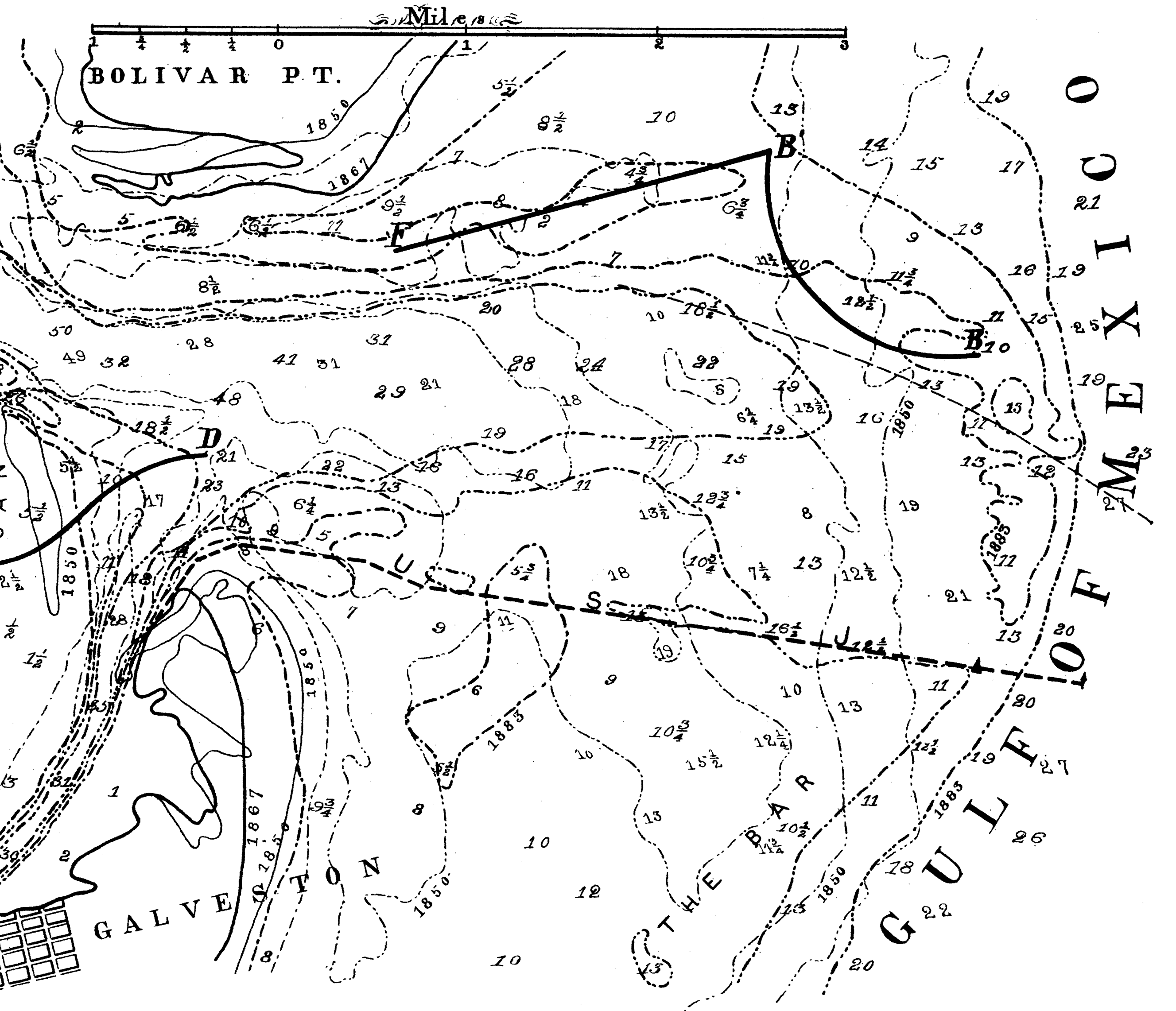


FIG _ II _



Miles
1 ¾ ½ ¼ 0 1 2 3
BOLIVAR PT.
PELICAN I.
GALVESTON
THE BAR
GULF
B
F
D
K

FIG _ II _



basin is generally composed of three subdivisions, viz: One extending along the islands on either hand, and one stretching to the rear. At the ebb of the tide the prisms of discharge are all approaching the gorge at the same time. In consequence of the inward flexure of the spit at this place, one or both of the lateral currents are reflected into the face of the main discharge, and thus diminish its energy, which it is the object of the engineer to conserve.

These general effects can be seen by a comparison of the position and depth of the bar crossings along the coast line of the Middle and Southern States. One of the most striking and typical instances of the effect of the internal concentration and conservation of energy is that of the *Port Royal* entrance, where there is a depth of twenty-one (21) feet on the bar, due to the increased intensity of the resultant ebb, produced by the confluence of the Beaufort, Broad and Chechessee rivers, whose thalwegs approach in directions nearly parallel. Here, too, is observed the flexure of the outer stream to the southward, showing clearly the existence of an excess of flood action from the northward, and the piling up of sand banks on this side to be eroded by the ebb.

The opposite effect resulting from conflicting internal currents is illustrated in the case of the Galveston entrance (Fig. 2).

An examination of the various entrances leaves no doubt of the existence of such a littoral flood movement, whereby the sands of the beaches are transported to and deposited in front of the inlets, where the racing waves, no longer resisted by and reflected from the shore, escape through the break in the barrier which forms the outlying sandy cordon defending the coast.

Ocean Dynamics.

The effect of this racing of the waves in search of an escape from the pressure of the flood tide is to scour off and prolong the sharper lip at the gorge and to flatten out and beat back the opposite shore, thus shifting the position of the "inlet" until in some instances it is transported considerably to one side of the medial line of the inner bay, or entirely closed. Thus, the position of the thalweg is made to cross the gorge obliquely, and furnishes additional evidence of the resultant direction of the external or flood movement. *These movements are fully illustrated in the comparative chart herewith submitted of Barnegat Inlet (Plate IV), from which it is seen that the flood resultant comes in from the north, prolonging and eroding the northern spit compressing the ebb against the lighthouse shore, from which it has cut away so great a volume as to seriously endanger the structure. The total movement in about thirty-four (34) years has been half a mile, or about eighty (80) feet per year. Had this action been previously recognized the lighthouse would probably not have been placed in so dangerous a position, but on the north spit. During the prevailing north-east winds of this spring the encroachments have been more rapid and extensive than at any previous time. The remedy is apparent, but will be stated generally further on in this communication. The effort of the ebb is not to oppose the flood resultant directly, but to turn away therefrom and assume a direction as nearly as may be at right angles thereto.

Thus the flood will roll the sand up the gentler outer slope to the crest in a direction normal to the main channel, while the ebb will sweep across its path on the line of least resistance,

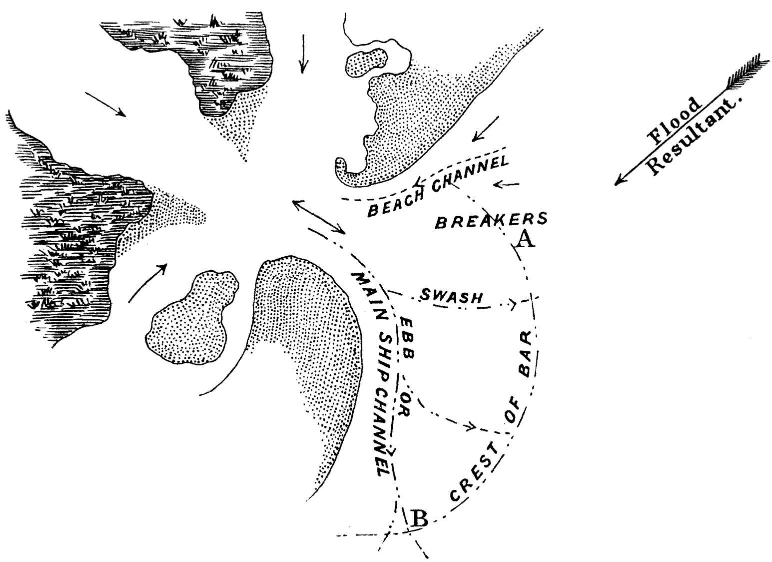
*This paragraph was interpolated here after the paper was written. See Supplement.

which lies behind and parallel to the barricade formed by the flood, and effect *its maximum result at the point of minimum resistance*, which is that point of the bar farthest removed from the direct action of the flood. This enceinte formed by the flood is also the cause of the beach channel lying under the near spit, since a portion of the flood is deflected by the bar into the re-entrant between it and the shore, whilst another portion is rolled along the beach, and these two components unite in a resultant cutting across the inner angle of the bar and carrying silt into the gorge.

The action of these forces may possibly be made clearer by reference to a simple diagram:

A. Point of maximum flood force.

B. Point of minimum flood resistance.



The Tidal Movements Producing These Phenomena.

Thus far I have been considering the local features, and deducing therefrom the *general condition* of the hydrodynamic

forces which have produced the observed effects. It now remains to determine why this resultant should be sometimes from the north-east and at other times from the south-east. This leads at once to an examination of the phenomena attending the approach of the tidal wave and the position of the cotidal lines with reference to the coast line. For this purpose there are available the general cotidal maps of Prof. Guyot, and the more detailed maps of Prof. Bache, accompanied by the tide tables of the Atlantic coast, as contained in the United States Coast Survey Reports. Meagre as these data are, they are yet sufficiently abundant to confirm the existence of the alleged resultant movements, and to verify in the most satisfactory manner the reliability of this method of determining the forces by their effects.

Although the phenomena of tidal movements in the open ocean are but little understood, it is well known that they are sensibly modified by the topography of the coast line.

Professor Bache says that " where a bay or indentation of the coast presents its opening favorably to the tidal wave and decreases in width from the entrance towards its head, it is well known that the tides rise higher and higher from the mouth upwards," while Lentz, in his "Ebb and Flow of the Tides," says:

"The intricate, theoretical, tide-generating conditions are complicated by a number of circumstances, forming a bewildering labyrinth of causes and results, through which the human mind cannot find its way."

" The numberless tidal waves rushing through the ocean in all directions may be compared to those formed by throwing ten (10) or twenty (20) stones into a small pond. By watching these we may learn as much as we know about the tidal waves moving on our ocean," and he adds, " this certainly is discour-

aging, and we only know that we do not know anything." While this conclusion may be true as to the currents in the open sea, it cannot be applied to those along shore, for an examination of our coast line reveals some striking and definite features. These are, the existence of four (4) prominent salients upon which the tidal crest impinges, and by which it is broken up into components, which are deflected into the bays on either side. At the points of incidence there will generally be found large inner sounds, extensive shoals and bars, and the heavy precipitation resulting from the checking of the momentum of the wave, the change in its direction and the interference and eddies produced thereby. Then follows the comparatively smooth reach of straight beach, along which the component tidal waves travel inland from the chord joining the salient capes, and finally, the indented and serrated shore where the opposing components in the same sinus meet at the point farthest from the chord, and where the tides are highest, the marshes most extensive, and the outlying cordon of sand is replaced by numerous islands and intricate "back" channels. Here the tidal wave is brought to rest, and exerts its energy in a direction nearly normal to the coast, whilst along the flanks of the bay it is moving obliquely to the shore, but always towards the bight, except when locally disturbed, and with a dynamic energy, begotten in mid-ocean, which compresses the sand upon the shores and transports it *in the direction of that motion.*

The motor in the case of the flood tide is chiefly *universal* gravitation, which raises the crest of the flood wave from two (2) to five (5) feet, and rolls it forward upon our eastern coast line until its acquired momentum is met, modified and ultimately destroyed by the inertia of the mass of sand which it encounters.

So far as the ebb is concerned, it merely rolls off from the fore-shore, chiefly under the influence of *terrestrial* gravitation, and having its initial velocity at high-water line, its transporting energy is feeble, and it, therefore, exerts no material influence in modifying the *exterior* lines of the coast.

The Southern Bay.

These generalities are more clearly exemplified and confirmed by the facts exhibited on the accompanying chart (Plate III). Beginning at Cape Florida, the heights of the tides at the various external stations are marked in feet, whilst the cotidal lines are plotted as enlarged from the United States Survey Report of 1854.

By following the coast northwardly from Cape Florida, it will be found that the height of the tide increases from 1.5 to about 7.4 feet at Jekyl Island, between St. Simon and St. Andrew's Sounds, which is the most remote point, about two hundred (200) miles, from the chord of the arc; also, that the outer ends of the main or ebb channels are flexed northwardly, and that even the land drainage extends in the same general direction. As the bight of the bay is approached, the land discharge becomes more nearly normal to the coast and the shore line more deeply indented, and after passing this point, the tidal elevations decrease (with one exception), the directions of the land and channel discharges are reversed and the shore lines become smoother. This reach of coast is characterized by three secondary bays, separated by the groins of Cape Lookout and Cape Fear. These capes are the resultants of the opposition of the tidal wave to the fresh water discharge, which being unable to effect its escape in the face of the flood is turned to the west and south by the pressure of the

tidal component deflected from Cape Hatteras. An inspection of any general map of North Carolina reveals the fact that instead of the rivers being normal to the coast, they are turned for considerable distances back from their mouths into a direction nearly parallel with the shore line, and effect their discharge under the lee of the Cape, thus *conforming to the general law of least resistance.*

The capes and bars thus formed by the parallel and confluent fresh and salt water currents deflect the littoral component until it is met by the direct flood crest and returned to the beach near the middle point of each of the three (3) bays, Raleigh's, Onslow's and Long's. Here it is resolved into secondary littoral currents along the ellipses thus formed. The eastwardly components of these waves compress the *ebb channels against the eastern shores* of the outlets, as at Beaufort, N. C., while those to the westward, reinforced by the original wave, race along the beach, closing or shoaling the inlets and forming with the land drainage the long spits above described.

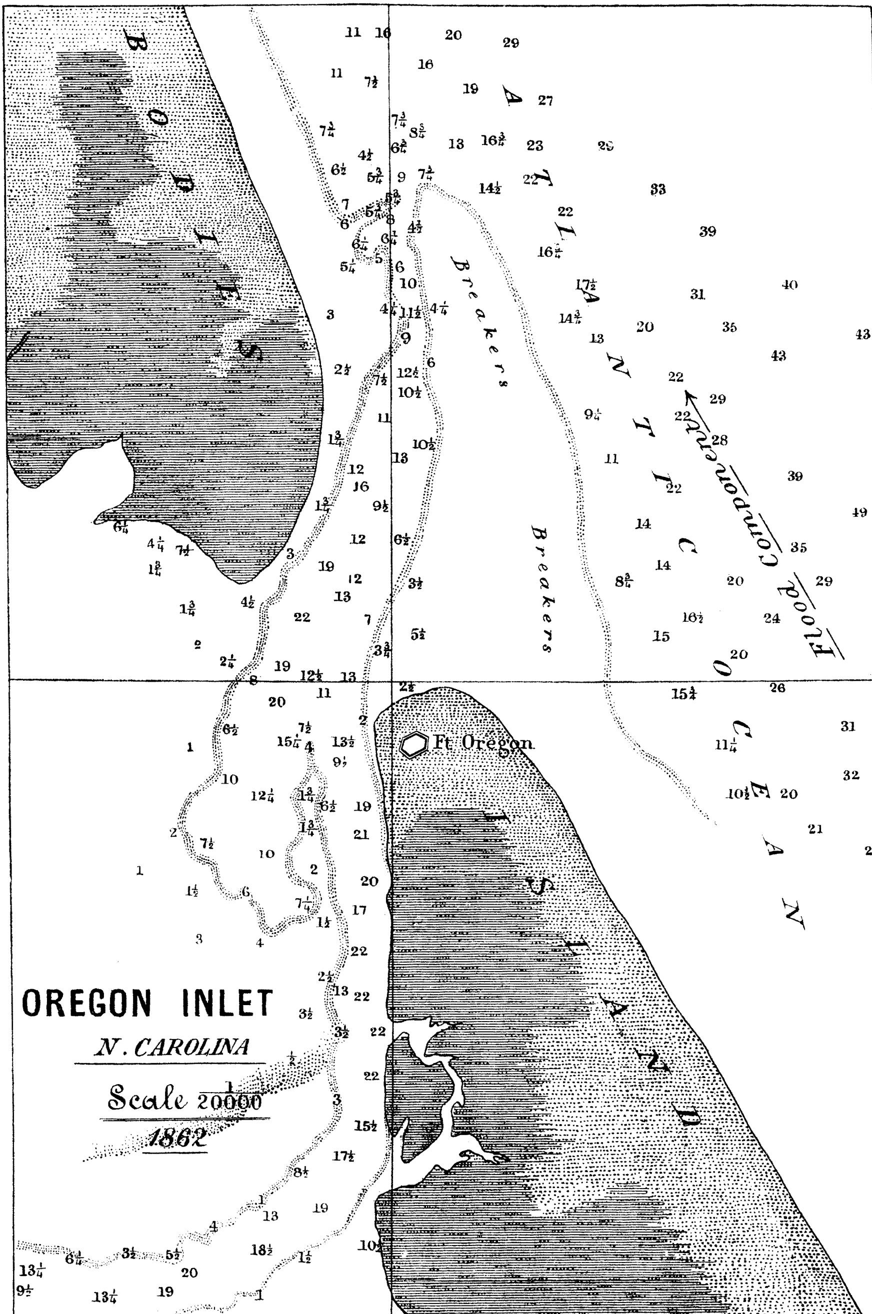
The time of high water is also much earlier outside or to the eastward of the cape than it is within, in consequence of the circuitous route required to be taken by the flood. The suction thus produced causes a draft current to the eastward, which deflects the ebb discharge from the inlets in this latter direction and increases the height of the tides inside the capes.

It is also a notable fact that a straight line drawn from Cape Roman to Hatteras is just tangent to Capes Lookout and Fear, and that the transverse and semi-conjugate axes of the ellipses of Long and Onslow Bays are respectively equal, while Raleigh Bay is somewhat smaller in both directions and has a steeper scarp than either of the others (due to the incident wave). The shore to the north of Cape Hatteras is deflected from the chord of the three bays produced at an angle of 45° for a dis-

tance of twenty-six (26) miles, when it again bends to the westward through an angle of 30°, and continues in an unbroken stretch of ninety-four (94) miles to Cape Henry. The only outlets on the eastern cordon of Hatteras are near the point of deflection where the northward component from the cape and the normal wave commingle.

The cotidal curve of eleven and one-half ($11\frac{1}{2}$) hour interval envelopes the cape in an arc of a circle whose radius is seventy-three (73) miles, whilst the shore line changes its direction through an angle of 74°. The limiting radii of this sector also pass through the main openings of the cordon at Oregon and Ocracoke Inlets, which are opposite the tangent points of the arc, and hence indicate the locus of the change of direction and weakening of the tidal wave. The coast line will also be found to be inclined to these radii at an angle of 80° which indicates the direction of the shore component at the points of intersection. At Ocracoke the chord of the bay lies 10° north of the tangent, and at Oregon (Plate II) 10° to the west, showing the movements to be east and north.

The velocity of the wave is greatest along the normal at Cape Hatteras and least along the radii limiting the sector. An examination of the interval between the cotidal lines shows also that the rate of movement of the general crest is considerably retarded as it approaches the shore. The twelve (12) hour crest will be seen with its flanks rolling along the receding shores of the bays, as already described. The earliest points of contact of the tidal wave are readily discovered from this chart to be at or near the points formerly indicated in this paper, whilst the latest point is at Jekyl's island, which is found by measurement to be just midway between Capes Florida and Hatteras, thus making the times of transit to this point of meeting of the flood components, equal.


OREGON INLET
N. CAROLINA
Scale $\frac{1}{20000}$
1862
BODIES
ISLAND
ATLANTIC OCEAN
Breakers
Breakers
Ft Oregon
Flood Current

THE MIDDLE BAY

Extends from Cape Hatteras to Nantucket, a distance of about five hundred and forty (540) miles. Its longest ordinate is that opposite the New York entrance, where it is one hundred and forty (140) miles. The shore line from Cape Henry to Sandy Hook being nearly parallel to the chord and being broken by the two large bays of Chesapeake and Delaware, there is not so great a compression of the two converging tidal components as was observed in the southern bay, yet the same general characteristics are observable.

Proceeding north from Hatteras, there is the long sandy cordon, with its smooth beach stretching in an almost unbroken curve to Cape Henry at the mouth of the bay. Here the flood wave is interrupted and deflected by the opposing Cape Charles, the outer shore line of which is deeply scored by sounds and studded with islands and shoals, created by the flood which cushions upon it. The northern component from Cape Hatteras practically terminates here and is dissipated by the bay and the islands of the outer coast as far up as Paramores Bank. In a similar manner the component rolling westerly from Nantucket, is absorbed by Long Island Sound and New York and Raritan Bays. The normal flood wave approaching the coast on either flank of Delaware Bay is resolved by the most salient points of New Jersey and Virginia into littoral components one of which travels from a point north of Barnegat, northward to Long Island. It is this component which has created and maintained Sandy Hook and which is eroding the beach at Long Branch. (The westwardly, or Long Island component has made the spit at Coney Island, and the resultant of both, maintains the flood channel under this point.) The other or New Jersey component moves towards Cape May

and builds the bars in front of Barnegat, Absecon and other inlets, crowding the channels over against the southern shores of these inlets, which are thus eroded by the ebb currents.

The same physical features will be found to result from the components acting north and south from a point near Green Run Inlet, Md., on the coast between Cape Charles and Henlopen.

The tidal observations in this bay are indicated on the map (Plate III) and confirm this theory. The mean rise of the tide at Cape Charles is only 2.5 feet, because of the relief afforded by the bay. At Cold Spring Inlet it is 4.4, and at New York entrance 4.8. Here it attains its maximum height and thence diminishes eastwardly to Nantucket. From the secondary point of reversion near Barnegat on the New Jersey coast, the littoral currents are indicated by the heights of the tides. Thus at Barnegat they are 2 feet, at Absecon 3.9, at Cold Spring 4.4, etc.

The interference of the tidal waves and the great difference of three (3) hours in the time of high water which is compressed in the short space between Martha's Vineyard and Monomoy, is too extended a subject to be included in this paper, which is intended merely for the alluvial coast line south of Long Island. Its consideration is therefore omitted, but the mean tides are recorded in part of the northern bay to illustrate the continuance of the concentration of the tidal energy and progression as previously observed.

These same laws and phenomena are found to exist on the Pacific Coast and will explain many of the effects which have only been casually noted by mariners. The phenomena are identical with those already described. The laws are of general application.

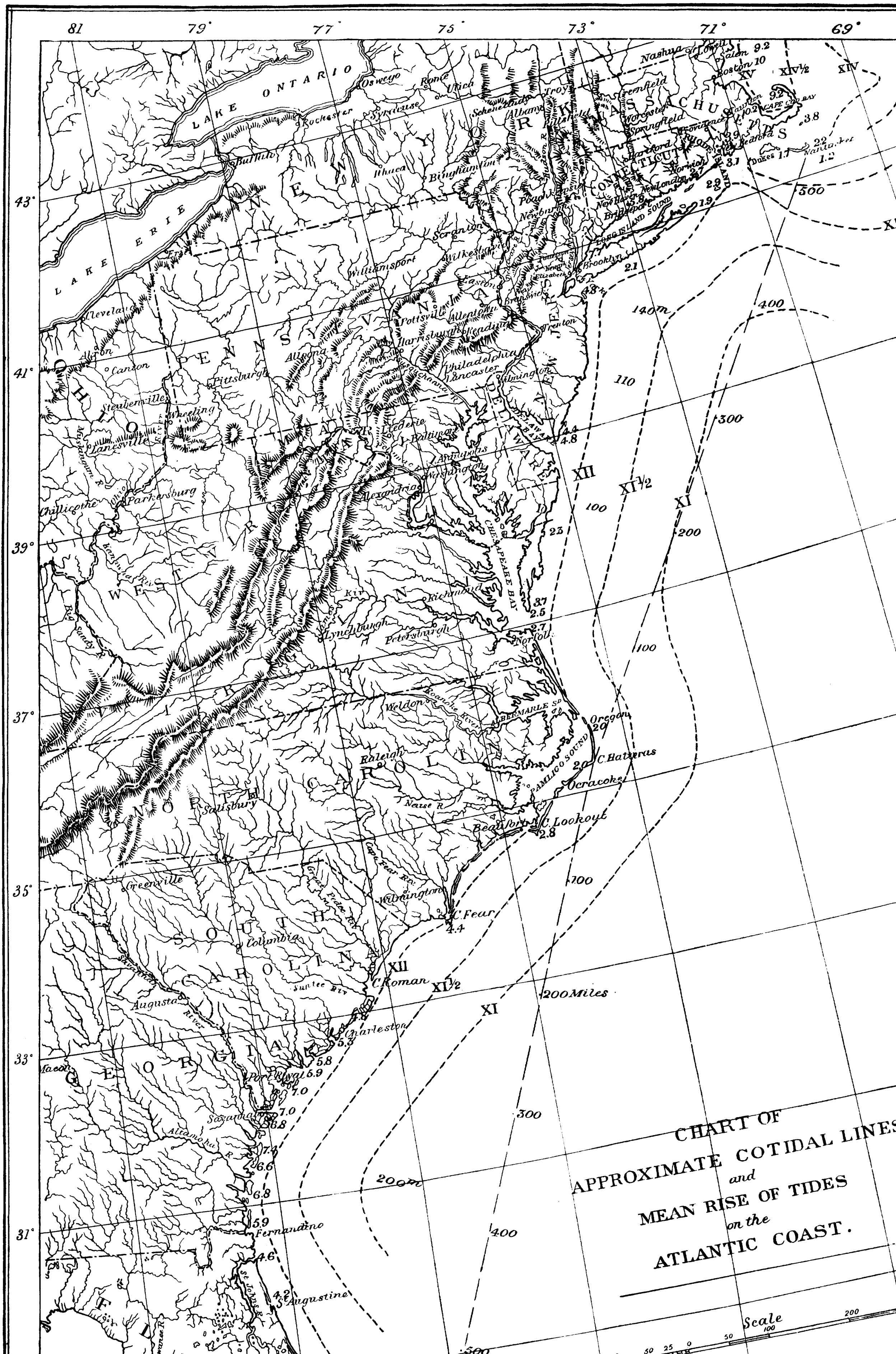
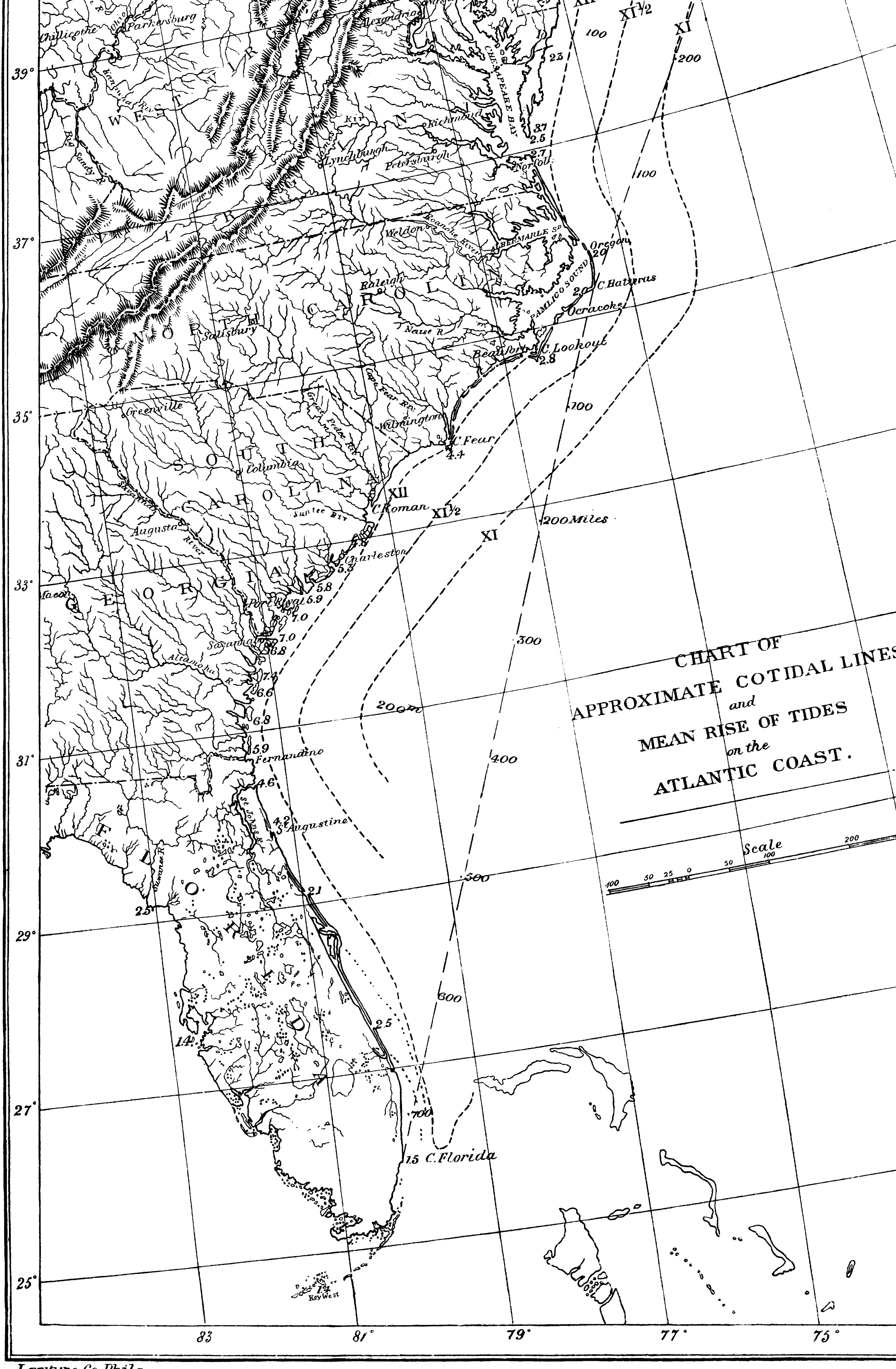


CHART OF
APPROXIMATE COTIDAL LINES
and
MEAN RISE OF TIDES
on the
ATLANTIC COAST.
Scale
81
79°
77°
75°
73°
71°
69°
43°
41°
39°
37°
35°
33°
31°
LAKE ONTARIO
LAKE ERIE
NEW YORK
MASSACHUSETTS
CONNECTICUT
RHODE ISLAND
PENNSYLVANIA
NEW JERSEY
DELAWARE
MARYLAND
OHIO
WEST VIRGINIA
VIRGINIA
NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
Oswego
Rome
Utica
Syracuse
Rochester
Buffalo
Ithaca
Binghamton
Schenectady
Albany
Troy
Pittsfield
Greenfield
Worcester
Springfield
Lowell
Nashua
Salem 9.2
Boston 10
Hartford
Providence
Norwich
New London
New Haven
Bridgeport
Newport
New Bedford
Nantucket
Dukes
CAPE COD BAY
LONG ISLAND SOUND
Brooklyn
Poughkeepsie
Newburgh
Scranton
Wilkesbarre
Williamsport
Easton
Allentown
Reading
Pottsville
Harrisburgh
Altoona
Trenton
Philadelphia
Lancaster
Wilmington
Cleveland
Akron
Canton
Pittsburgh
Steubenville
Wheeling
Zanesville
Parkersburg
Chillicothe
Baltimore
Annapolis
Washington
Alexandria
CHESAPEAKE BAY
Richmond
Lynchburgh
Petersburgh
Norfolk
Weldon
Roanoke River
ALBEMARLE SD
PAMLICO SOUND
Oregon
C. Hatteras
Ocracoke
Raleigh
Neuse R.
Beaufort
C. Lookout
Salisbury
Greenville
Cape Fear Rr.
Wilmington
C. Fear
Columbia
Santee Rr.
C. Roman
Charleston
Augusta
Savannah River
Port Royal
Savannah
Altamaha R.
Fernandino
St. Augustine
St. Johns R.
Macon
XV
XIV½
XIV
XII
XI½
XI
100
110
140m
200m
200
300
400
500
200 Miles
2.1
4.8
4.4
2.3
3.7
2.5
2.7
2.0
2.8
5.3
5.8
5.9
7.0
6.8
7.4
6.6
5.9
4.6
4.2
3.1
2.9
1.9
3.8
2.2
1.2
1.7
10.2


CHART OF
APPROXIMATE COTIDAL LINES
and
MEAN RISE OF TIDES
on the
ATLANTIC COAST.
LAKE ONTARIO
NEW YORK
PENNSYLVANIA
MASSACHUSETTS
CONNECTICUT
RHODE ISLAND
NEW JERSEY
DELAWARE
MARYLAND
VIRGINIA
NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
CHESAPEAKE BAY
DELAWARE BAY
LONG ISLAND SOUND
ALBEMARLE SD
PAMLICO SOUND
C. Hatteras
C. Lookout
C. Fear
C. Roman
Boston
Providence
New London
New Haven
Brooklyn
Philadelphia
Baltimore
Washington
Norfolk
Richmond
Charleston
Savannah
Fernandino
St Augustine
Scale
300 STAT MILES
200 Miles



Levytype Co. Phila.

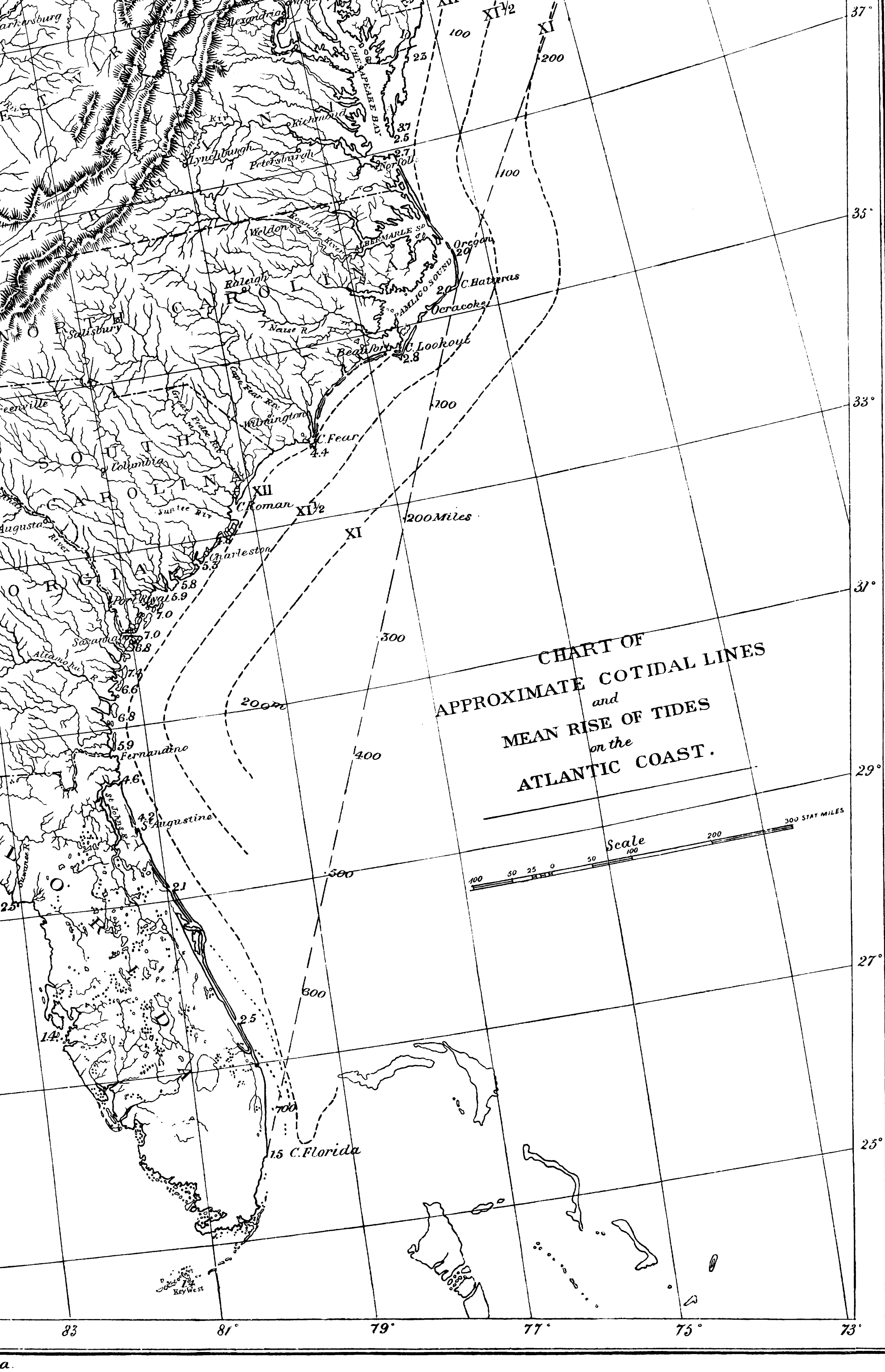


CHART OF
APPROXIMATE COTIDAL LINES
and
MEAN RISE OF TIDES
on the
ATLANTIC COAST.
Scale
300 STAT MILES
Parkersburg
Alexandria
CHESAPEAKE BAY
Richmond
Lynchburgh
Petersburgh
Norfolk
Weldon
Roanoke River
ALBEMARLE SD.
PAMLICO SOUND
Oregon
C. Hatteras
Ocracoke
Raleigh
Neuse R.
Beaufort
C. Lookout
Salisbury
Cape Fear Riv.
Wilmington
C. Fear
Columbia
Santee Riv.
C. Roman
Augusta
Charleston
Port Royal
Savannah
Altamaha R.
Fernandino
St. Johns R.
St. Augustine
C. Florida
Key West
200 Miles
XII
XI½
XI
37°
35°
33°
31°
29°
27°
25°
83
81°
79°
77°
75°
73°

a.

THE JETTY SYSTEM AS AT PRESENT APPLIED.

In applying tidal scour to the improvement of harbor entrances in the United States, these three (3) principles have been laid down as fundamental:

1. The works should be so designed that "*they should not impede the inflow to such an extent as to prevent the tidal basin being filled at every influx of the tidal wave.*"

2. "*They should control the outflow to such a degree and in such a manner that a channel of the required depth will be maintained through the bar.*"

3. "*They should not to any considerable extent, cause a movement seaward of the main body of the bar; that is, the general position of the bar should be independent of the effects produced between and beyond the heads of the jetties.*"

The attempt to reconcile these conflicting conditions as to concentration of ebb and free admission of flood resulted, after mature consideration, in a plan involving low or submerged jetties, which were tried as an experiment both at Charleston and Galveston. The result has been to push the body of the bar seaward, without at the same time materially deepening the water on its crest. The cost of these experiments has reached nearly $3,000,000.

These plans are defective, not only in their failure to depress the plane of tidal scour over the bar, but they are so designed as to divert the ebb stream directly into the face of the flood, where the resistance to be overcome is the greatest. The plans for Galveston have been modified, and it is now proposed to raise the jetties to high water, at an estimated cost at this port alone of $7,000,000. But even if this be done upon the two

lines as proposed, there will still be the serious violation of the first of the above established principles, and the further serious objection of directing this diminished tidal prism into the face of the flood, near its point of maximum energy, with nothing to lower the plane of tidal scour except the small amount of head due to contraction. This is in violation of the accepted rule that all works designed for river or harbor improvements should aid, rather than oppose, nature. To turn an ebb stream out of its natural bed and deflect it by jetties across a bar is to impose additional resistance; first, from the change of direction, and second, from the additional resistance opposed by the higher crest and steeper slope of the bar. There is also a less effective relative area of ingress due to the form of the converging jetties.

Unless there is a large augmentation of the tidal prism by land drainage or from some other source during the epoch of the flood, such works will not, in general, prove beneficial. The location of the mouth of the jetties and the general design of the works is evidence that the principles enunciated in this paper as to the action of the flood and ebb forces have not been, as yet, fully appreciated in the planning of works of this description. The South Pass jetties are subjected to totally different conditions, as the flood tide furnishes but a very small percentage of the ebb discharge.

General Requirements for Harbor Improvements.

From what has already been presented as to the origin of the bars and the relations that exist between the flood and ebb resultants, it must be evident that the engineer who proposes to aid nature must so design his *external* works as to *prevent the flood tide from carrying sand into the channel* to obstruct

the ebb and require more work of it for its removal. He should also see that *the ebb be not diverted from its course, but be protected and defended* by a line of detached breakwaters. This will further have the effect of *confining the ebb waters*, which would otherwise escape in the swash or weir channels, to the main stream, *and so concentrate their energy upon a single point of the bar, and that point the one where the bar-building forces are the weakest.*

This barricade should *not in general be joined to the beach at the shore end*, but there should be left a wide opening across that portion of the bar which corresponds to the flood or beach channel. This should be deepened by the concentration of the flood currents, and the sand carried through the gorge would make fast land inside of the spit. Its quantity could be regulated by the extent of the opening. Thus the tendency of the flood to build its own barrier upon which to break would be aided, and the ebb would be protected in its escape. It also appears that but one such line of breakwater would in general be required, and hence the cost would be materially reduced. As it would occupy a site already dangerous to vessels, it would not increase the risks to navigation, but on the contrary, as it would project above the surface, it would be a beacon as well as a breakwater, and would greatly diminish the difficulties of effecting an entrance by sailing vessels over the case of a double line of extended jetties with a narrow pass between them, especially if submerged.

Internal Projects.

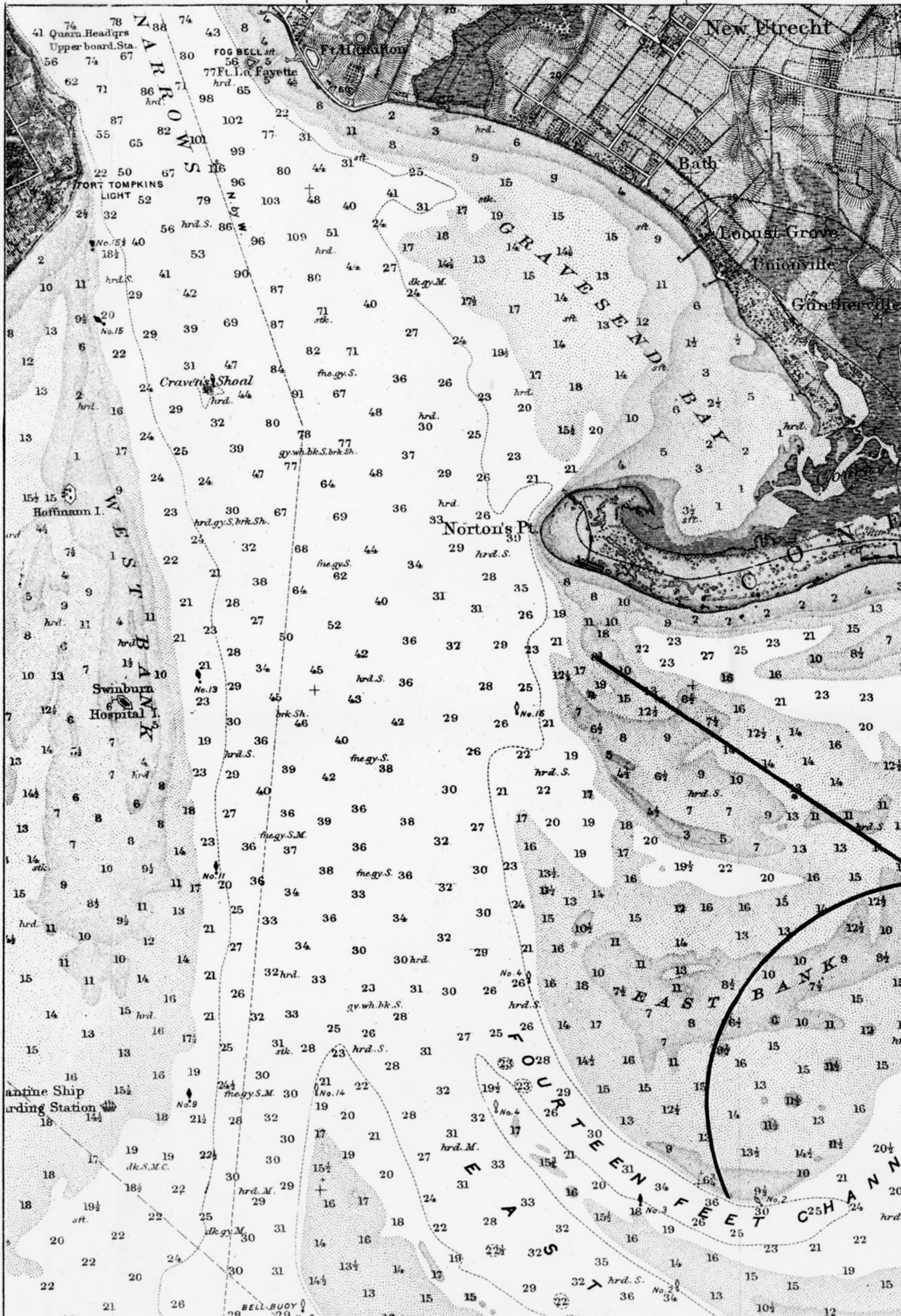
In connection with these external works there will be required in certain harbors regulating deflectors, or reaction dikes, to prevent the current interferences which produce hummocks, mounds, and even islands just inside the entrances

The position, extent and character of these works will depend largely upon the form and extent of the inner basin. Both the outer and inner lines should be so adjusted as not seriously to check the prevailing currents, nor produce shoals where they might be injurious to navigation.

The General Plan.

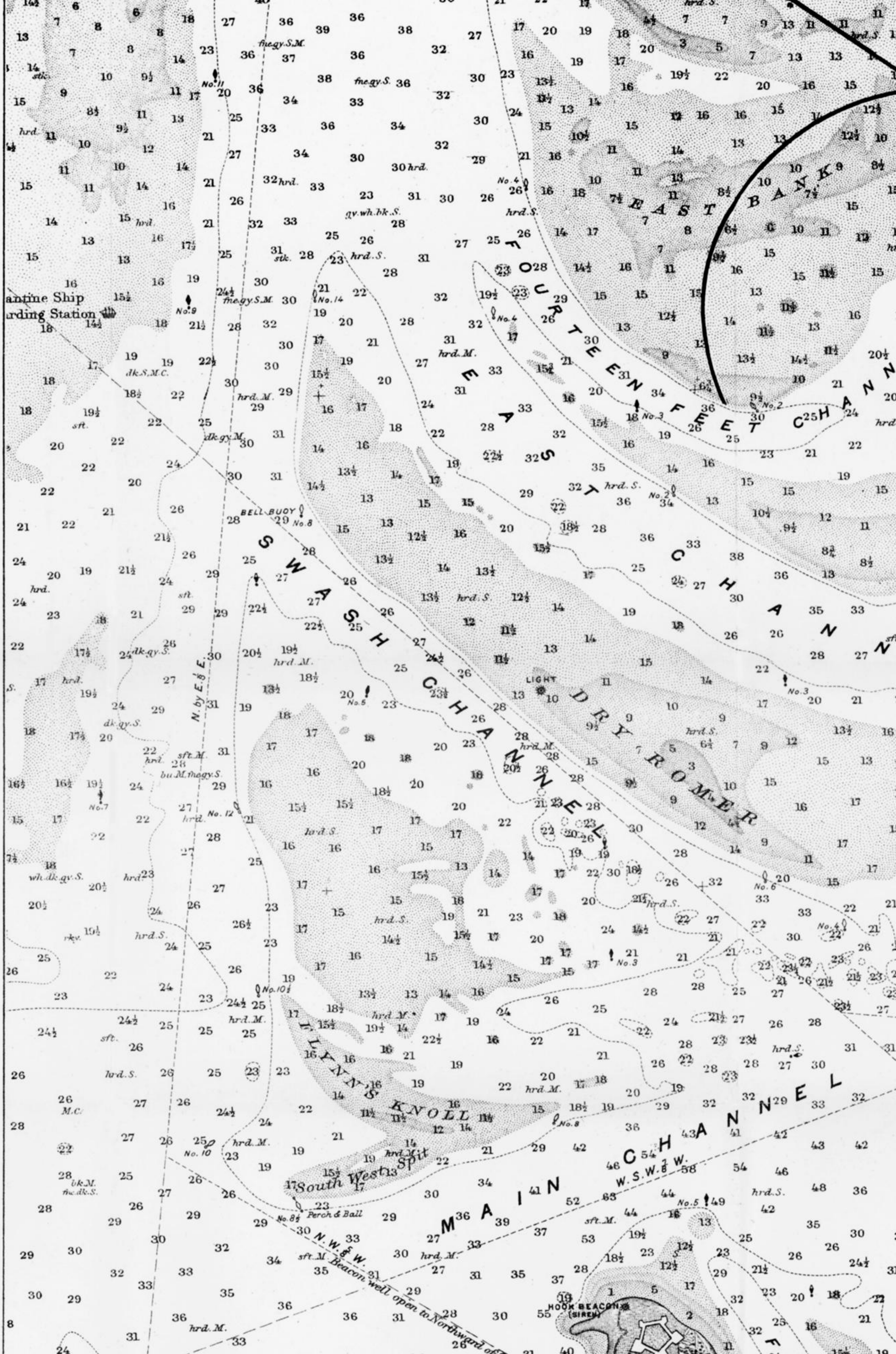
A typical plan for a breakwater which will not produce eddies or objectionable shoals, nor be eaten away by the sea, would be one composed of curves whose cusps are pointed in the direction of the advancing flood resultant, and having an inshore flank to concentrate the flood upon the beach channel, where it is both possible and desirable to maintain one. The curves should have the semi-conjugate diameters equal to about one-fourth ($\frac{1}{4}$) of the transverse. The interferences resulting from this *form* will produce shoals in front of the groins, thus reinforcing them, and as the outer end of the breakwater is pointed so as to receive the flood point blank, there will be no eddy nor any abrupt checking of its velocity inside to cause shoaling, yet the flood will be freely admitted and there will be a circulation created by having the beach end open. During the ebb there is no interference with the main current, but there is a concentration of its energy upon the weaker portion of the bar. For an illustration of this plan reference is made to the location on the chart of Charleston (Fig. 1), submitted herewith. The jetties, U. S. J. now under contract, cover a total length of six (6) miles. Those projected, of but three (3) miles, and the latter will make two (2) good channels, one for flood and one for ebb, while it is very doubtful whether the former will produce any material improvement of the entrance, but it will advance the general shore line and push the bar further to seaward.

02'   74° 00'

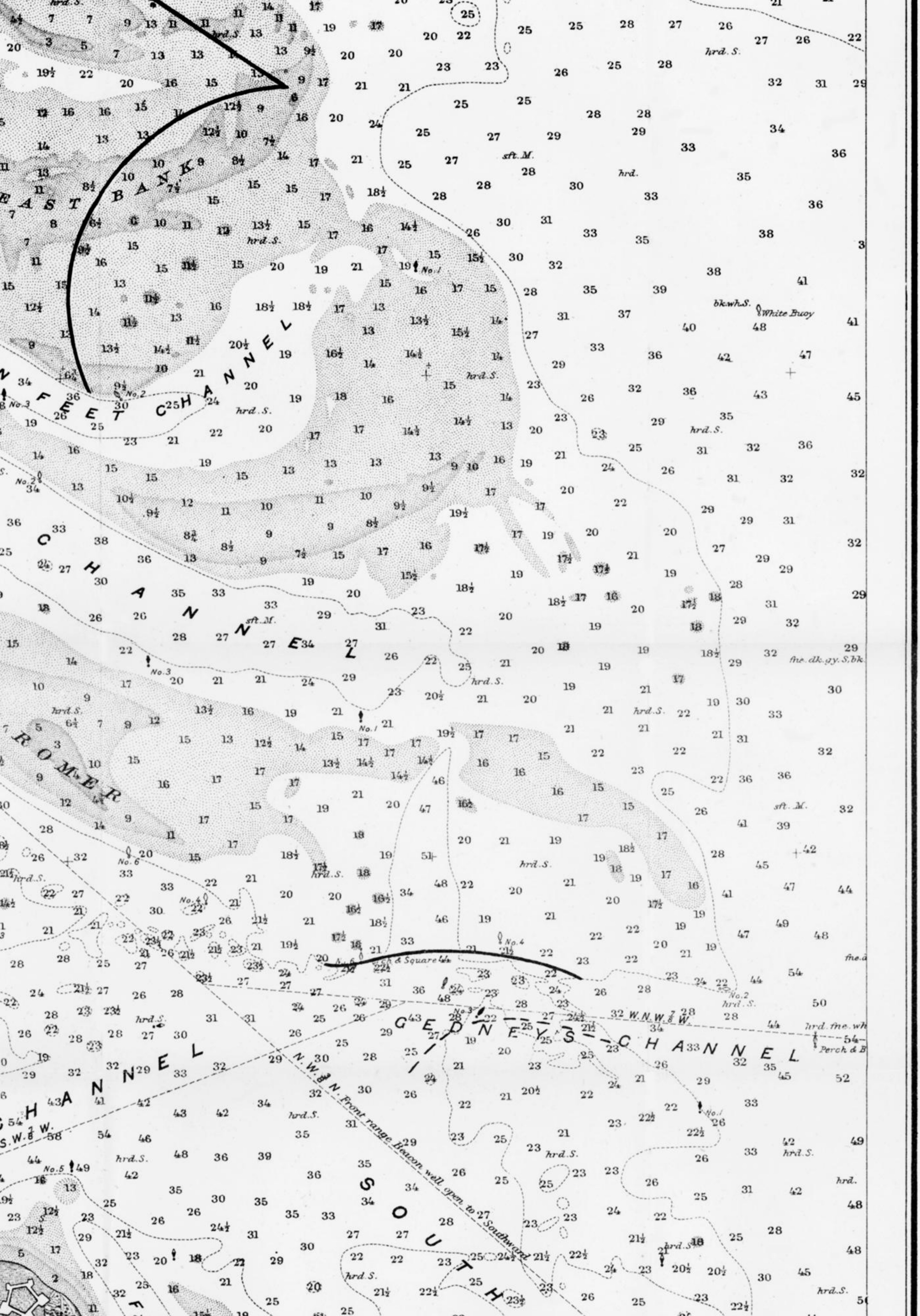


New Utrecht
Ft. Hamilton
FOG BELL
Ft. La Fayette
Quarn. Head'qrs
Upper board. Sta.
NARROWS
N by W
FORT TOMPKINS LIGHT
Bath
Locust Grove
Unionville
Gunthervill
GRAVESEND BAY
Craven's Shoal
Norton's Pt.
Hoffmann I.
WEST BANK
Swinburn Hospital I.
CONEY
EAST BANK
FOURTEEN FEET CHANN
EAST
BELL BUOY
Quarantine Ship Boarding Station

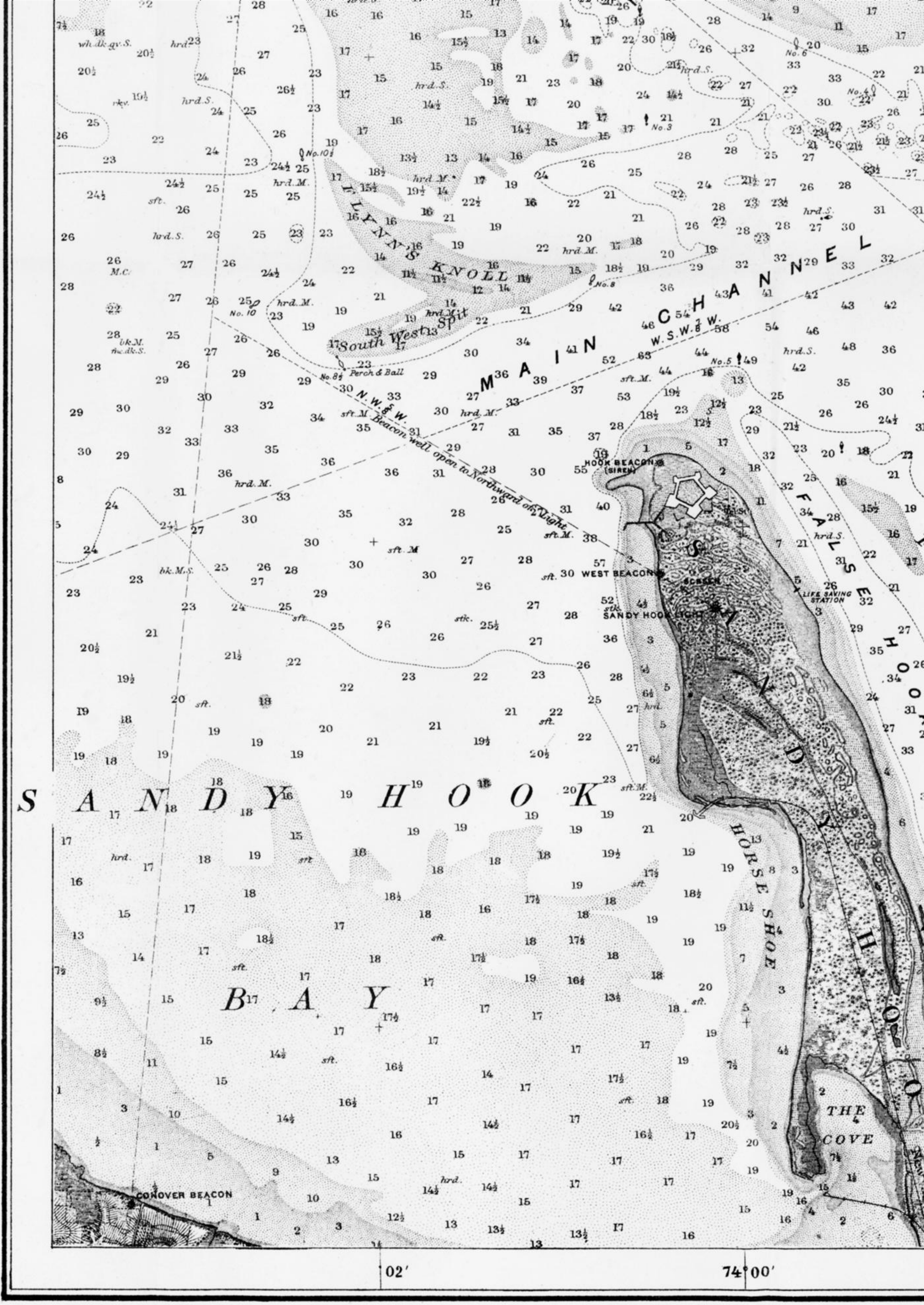
74° 00'
58'
56'
New Utrecht
Bath
Locust Grove
Unionville
Guntherville
Gravesend
Prospect Park Fair Grounds
SHEEPSHEAD BAY
CONEY ISLAND
Manhattan
Oriental
LIFE SAVING STATION
Brighton
Centennial Tower
Sub Breakwater
BAY
EAST BANK
FEET CHANNEL
White Buoy
No. 1
No. 2
No. 3



EAST BANK
FOURTEEN FEET CHANN
EAST CHANNEL
SWASH CHANNEL
DRY ROMER
FLYNN'S KNOLL
South West Spit
MAIN CHANNEL
BELL BUOY
LIGHT
HOOK BEACON (SIREN)
Perch & Ball
antine Ship
arding Station
N. by E. ⅝ E.
W.S.W. ⅞ W.
N.W.⅝W.
Beacon well open to Northward of



EAST BANK
FEET CHANNEL
CHANNEL
ROMER
GEDNEY'S CHANNEL
CHANNEL
SOUTH
N.W. b N. Front range Beacon well open to Southward
W.N.W. ⅞ W.
White Buoy
bk.wh.S.
hrd.S.
sft.M.
hrd.
fne.dk.gy.S.bk.
Perch & B
No.1
No.2
No.3
No.4
No.5
No.6
& Square



F. Moras lith. Phil.

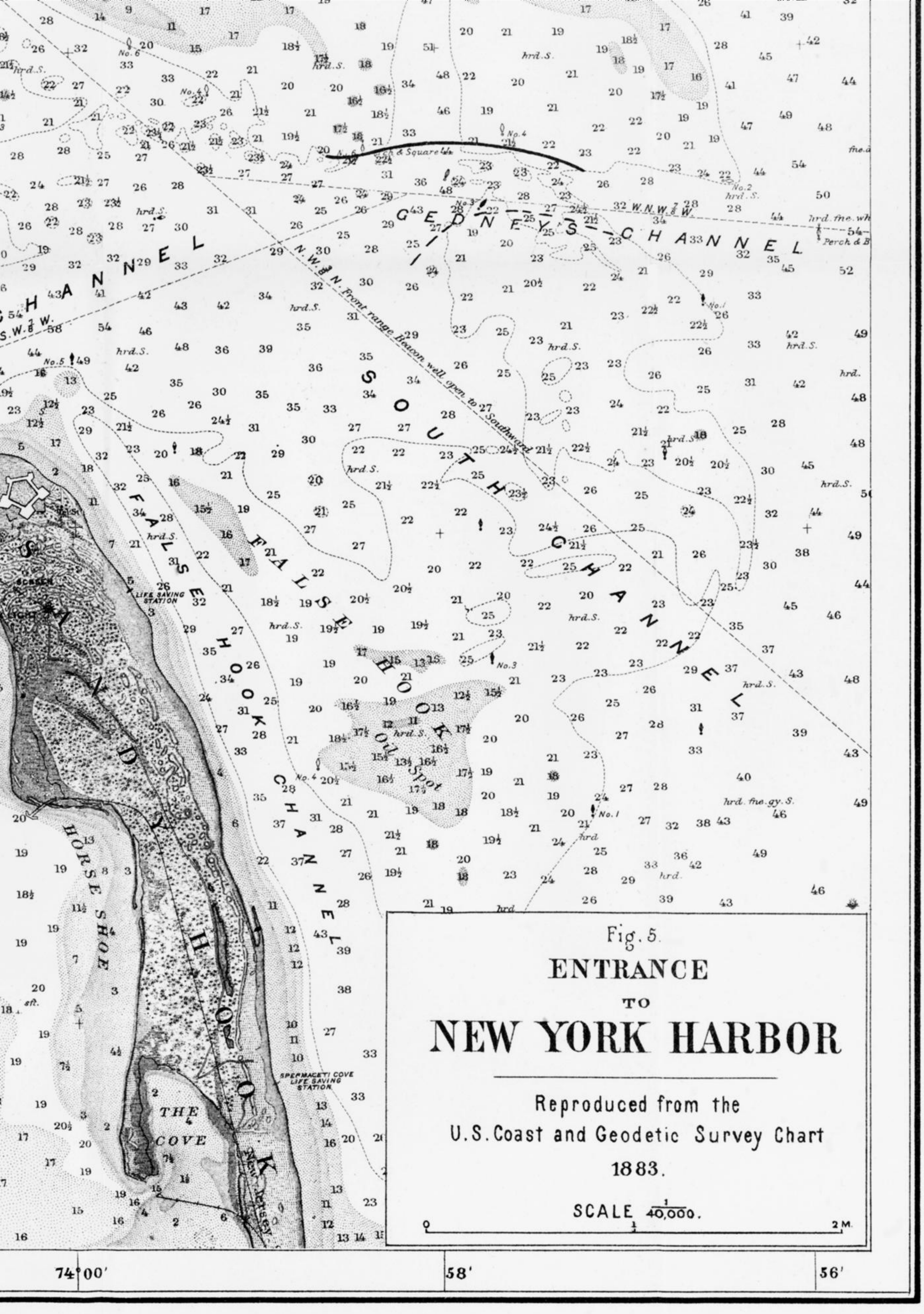


Fig. 5.

ENTRANCE

TO

NEW YORK HARBOR

Reproduced from the
U.S. Coast and Geodetic Survey Chart
1883.

SCALE $\frac{1}{40,000}$.

0 1 2 M.

The combination of this external barricade against the sand with the internal reaction dike for current concentration is shown in the chart of Galveston Harbor (Fig. 2), where the general direction of the movement is illustrated by the comparative shore lines and by the sand caught and held in the former channel by the south jetty. At the New York entrance (Fig. 5) similar effects are observed. Here the flood is compressed under the shore of Coney Island, where the beach channel is found, while the various ebb channels wind over the bar to the southward, increasing in depth as they approach Sandy Hook. The phenomenally deep basin on the bar at the head of Gedney's Channel is also seen. The plans as proposed for utilizing the existing natural forces for increasing the scour without obstructing any of the channels, are indicated by the heavy lines on the chart.

The Breakwater.

Jetties as now constructed are frequently composed of riprap stone of small dimensions, which lose nearly half of their weight when immersed. Hence they are easily displaced, and the work disintegrates. At Galveston the brush and stone jetties shrank or subsided during construction *61* per cent. The plans of the author propose to overcome this serious defect by constructing the breakwater of béton or other material constructed in barges, or on floats in the back channels, whereby the resistance of large masses will be rapidly secured to oppose the flood and protect the ebb. But the details of this method of construction do not properly constitute a part of this discovery. What is claimed as meritorious in this communication, and upon which the judgment of the Society is desired, is:

1. The determination of the character, direction and relative intensities of the forces acting upon any harbor entrance, from a study of the submerged topography and other local physical features.
2. The discovery of the existence of typical forms in the sandy spits bordering the entrance, which will in general indicate the direction of the resultant movement.
3. The recognition of the fact that the proper place for the ebb discharge, or channel over the bar, is as far removed as may be from the point of direct attack of the flood resultant, when the direction of the latter is not normal to the coast.
4. The definite enunciation of the principle that the trend of the coast with reference to the cotidal line will in general indicate at once the proper position for defensive works.
5. The presentation of an original form (in plan) of breakwater, whereby the natural agencies are materially *aided*, without serious interference with either the flood or ebb forces.
6. A method of improvement whereby the *internal* currents are concentrated and conserved for more efficient scour after passing the gorge.
7. A plan for utilizing the natural tendencies of the flood to cut a beach channel which shall be available for the lighter draught vessels.
8. The enunciation of the principle that the cause of the angular movement of the ebb stream after egress is due to the general form of the exterior coast line, which causes a racing of the tidal crests, from the outer capes towards the bight of the bay, and that the *flood components thus generated are the principal forces* which build the bars and shift the inlets. This incessant semi-diurnal action of the flood is *the controlling element* in the forces affecting

the magnitude and position of the bar. Storms and winds may modify and shift the deposits, but eventually the flood re-establishes the original conditions.

9. The free circulation and ingress given to the flood by the detached breakwater, so designed as both to oppose a portion of the flood and produce interfering waves which deposit sand outside of the channel whilst it also aids the ebb in its attack on the bar by defending its channel and concentrating its volume.
10. For a given site and stage of water the flood movement approaches in the *same direction*, hence the resisting and regulating works should be placed on the near side of the proposed channel. If on the far side, they would be worse than useless, unless for shore protection.
11. No artificial re-opening of an outlet which has been closed by this flood component, can be maintained without auxiliary works to deflect and modify its action. Dredging is only justified when the interests of navigation are sufficient to maintain a continuance of the expense and no other reasonable methods are available.
12. The ability resulting from these general principles to construct works requiring a lesser linear development which will produce greater navigable depths at less cost.
13. The abolition of the risks and difficulties attending the navigation of narrow jetty entrances in times of danger.
14. It frequently happens that the requirements of navigation and tidal concentration are conflicting, the former demanding wide entrances, the latter, on account of insufficient tidal volume, narrow ones. This debars the usual jetties and prevents improvement. The plans herein proposed are eminently adapted to meet such exigencies. As, for example, at Absecon Inlet.

Such being some of the practical results which it is claimed must follow from the discovery of the general direction and mode of action of the flood tide upon harbor inlets, an intelligent application of the principles should result in improving commercial intercourse, reducing the risks of navigation, lowering the rates of freight and insurance, and cheapening the cost of the construction of such works to the general government.

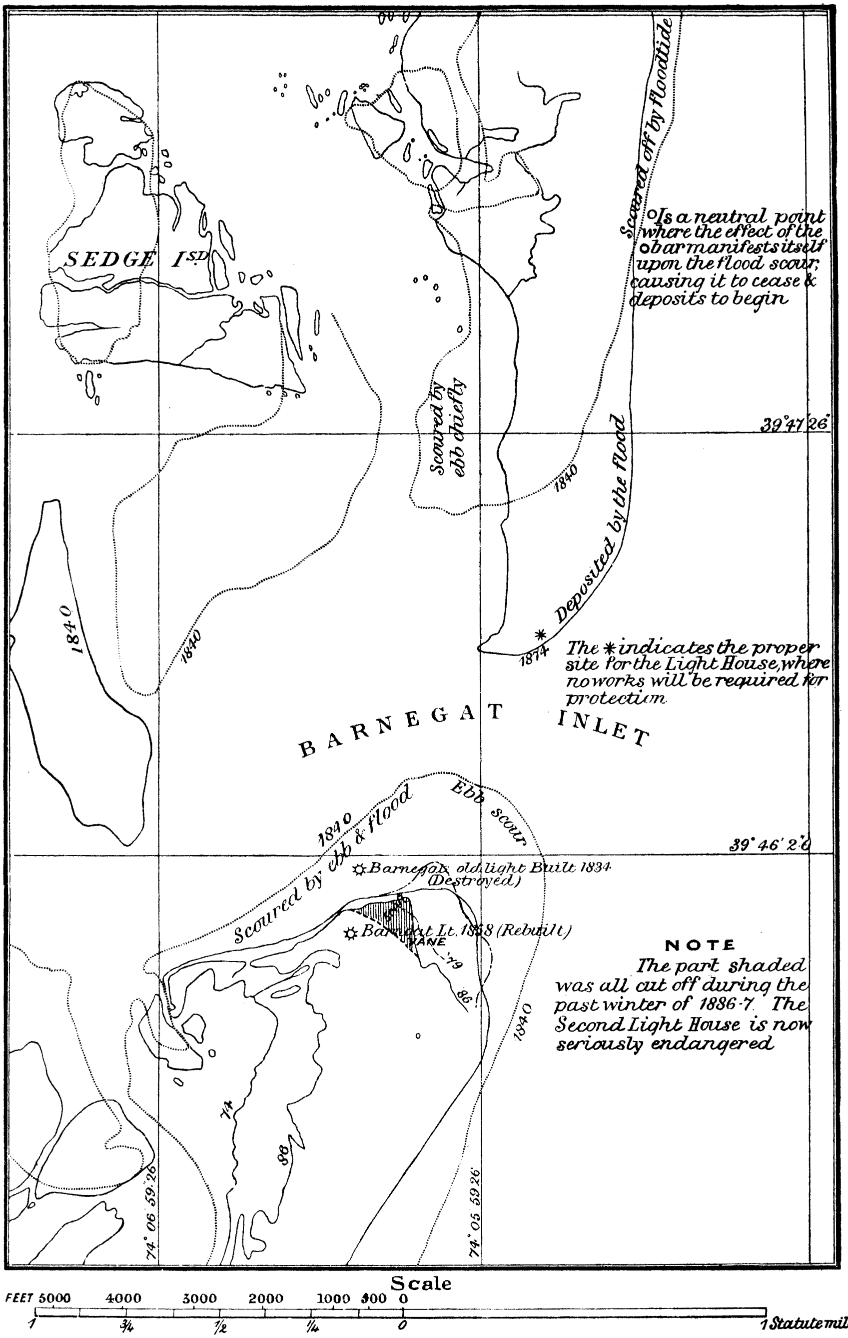
All of which is respectfully submitted for your consideration in compliance with a requirement of the By-Laws governing applications requiring an impartial but searching investigation.

Supplement to the Paper on the Physical Phenomena, Etc.

Since writing the above paper, I have seen and made a copy of a comparative survey chart of Barnegat Inlet, which so fully sustains the theory of the cause and direction of the movement and shows so conclusively the practical value of such knowledge that it is submitted herewith as additional information. The notes on the tracing, excepting the date of the surveys, are my own. They will sufficiently explain the directions of the movements without further elaboration.

It appears from this chart, that the lighthouse erected in 1834 was destroyed by the encroachments of the sea, presumably just prior to the construction of its successor in 1858. This would give an average rate of scour on the *inner* beach of thirty (30) feet per year, due to the retarded flood and ebb currents at this point.

To protect the present structure, which was placed about eight hundred (800) feet to the south, three (3) or more jetties


SEDGE Isd
Scoured off by floodtide
o Is a neutral point where the effect of the o bar manifests itself upon the flood scour; causing it to cease & deposits to begin
Scoured by ebb chiefly
39° 47' 26"
1840
Deposited by the flood
1840
1840
1874
The * indicates the proper site for the Light House, where no works will be required for protection.
BARNEGAT INLET
1840
Scoured by ebb & flood
Ebb scour
39° 46' 2·0
Barnegat old light Built 1834 (Destroyed)
Barnegat Lt. 1858 (Rebuilt)
VANE
79
86
1840
NOTE
The part shaded was all cut off during the past winter of 1886-7. The Second Light House is now seriously endangered
74
86
74° 06' 59·26
74° 05' 59·26
Scale
FEET 5000 4000 3000 2000 1000 500 0
1 3/4 1/2 1/4 0 1 Statute mile

were constructed on the beach to deflect these currents. As the ends of these structures were nearly normal to the currents, they created eddies, were soon undermined and gradually swallowed up by the sea, so that at present but a short stub remains. Thus these auxiliary works prove but temporary and ineffectual. Money is continually being expended in futile attempts to oppose the onward march of the sea which declines either to be flanked or resisted by shore-protection works placed on the obstructing spit. By a change of base to the north spit, the interests of navigation would, doubtless, be as well subserved and all the defensive works be rendered unnecessary. The proper site is indicated on the tracing by a star.

The same conditions existed but a few years since at Absecon Inlet, and they are continually recurring wherever the lights are on the spit opposed to the flood resultant.

So far as permanency of location is concerned, it becomes a very simple matter therefore to select the proper site. The local interests of navigation may require it to be nearer the ebb channel. If, however, the flood or beach channel is improved by the form of breakwater proposed in this paper, the light may be placed on or just in rear of this structure, which from its *form* will not scour deep holes to undermine its flanks, as they do not cross the path of the flood or ebb normally, or even at a considerable angle, and thus the ability readily to locate a lighthouse where it will not be eroded, is another of the practical benefits resulting from this discovery.